Particle Production at High p_T

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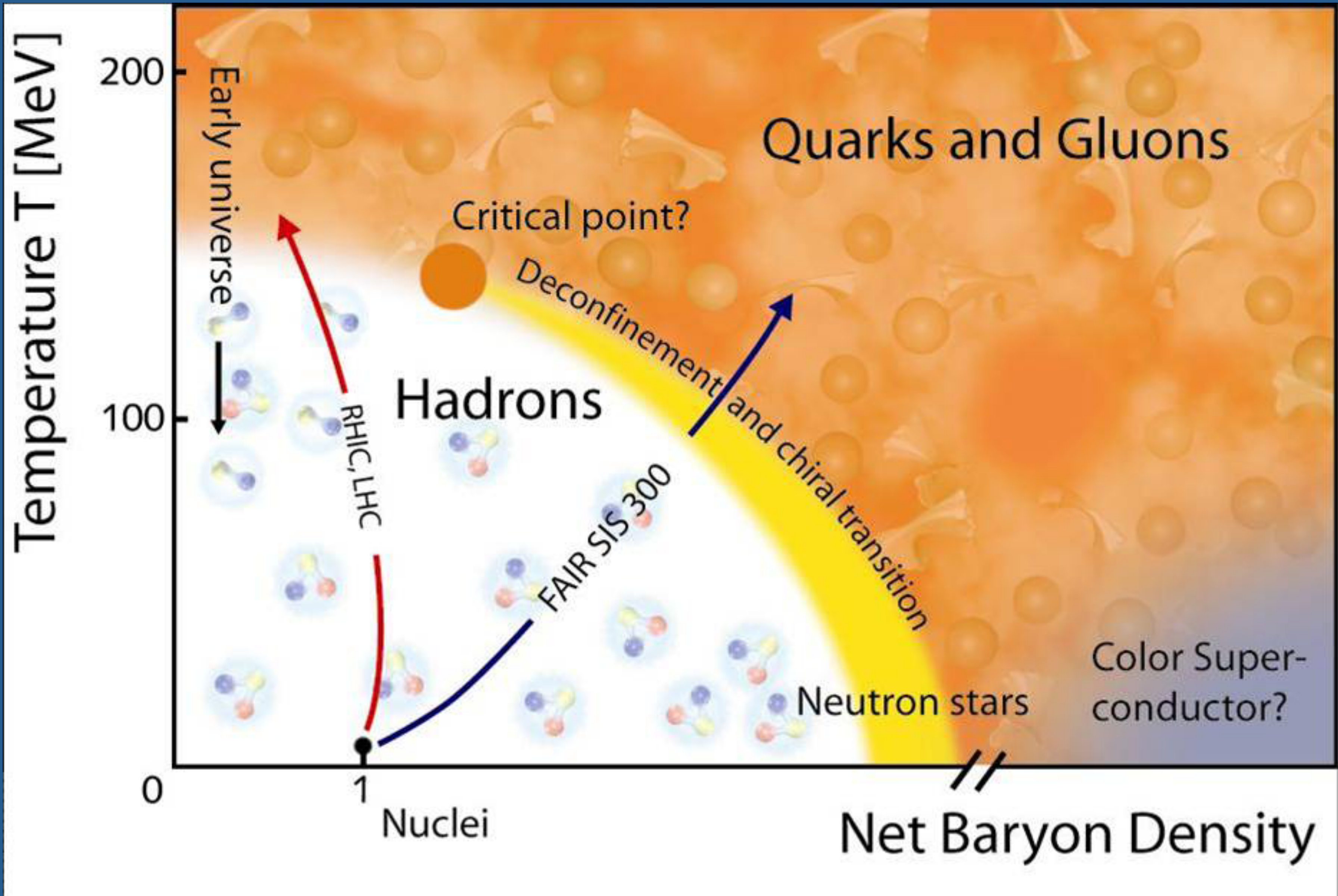
Hirschegg 2012

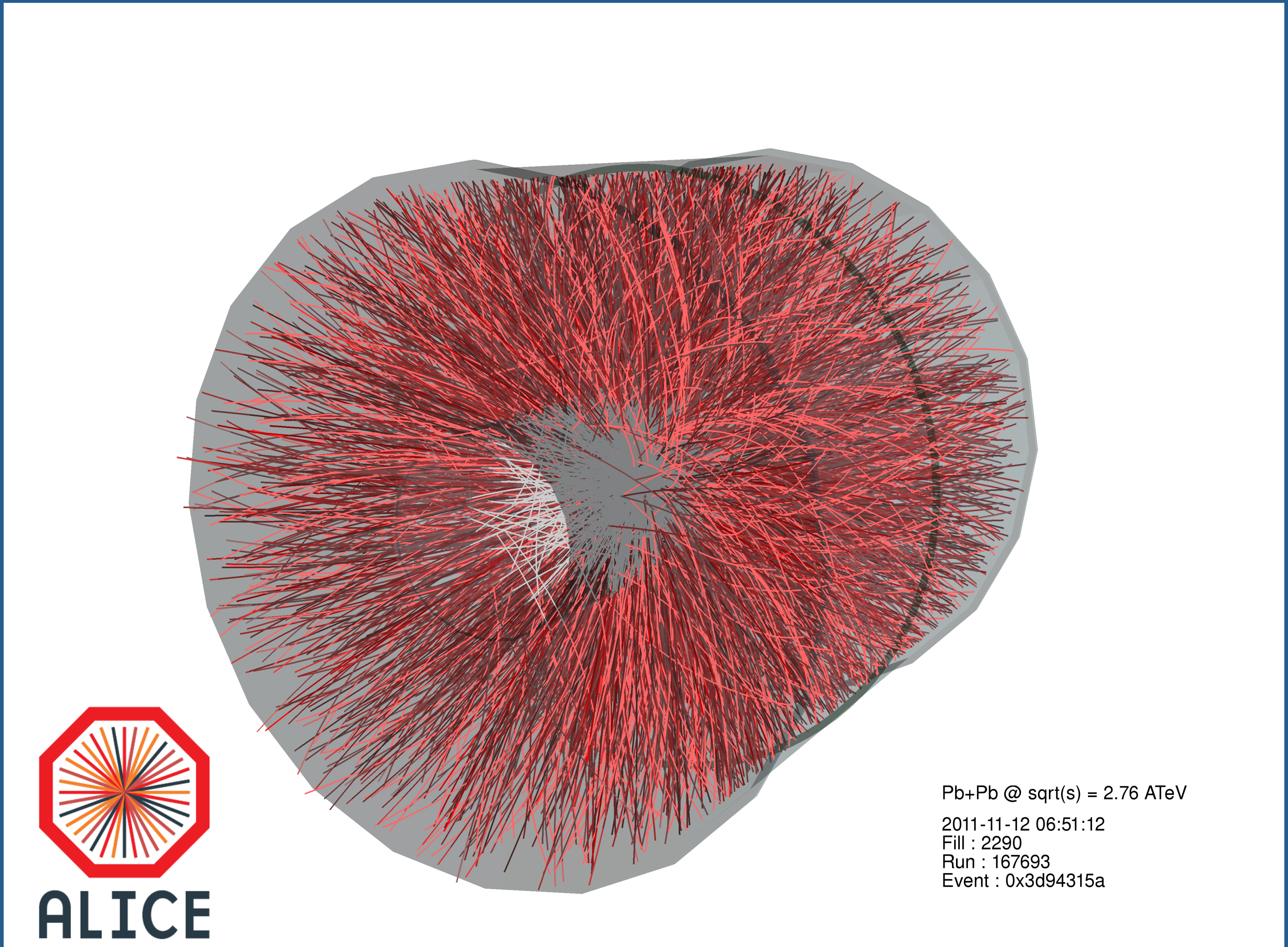
EMMI

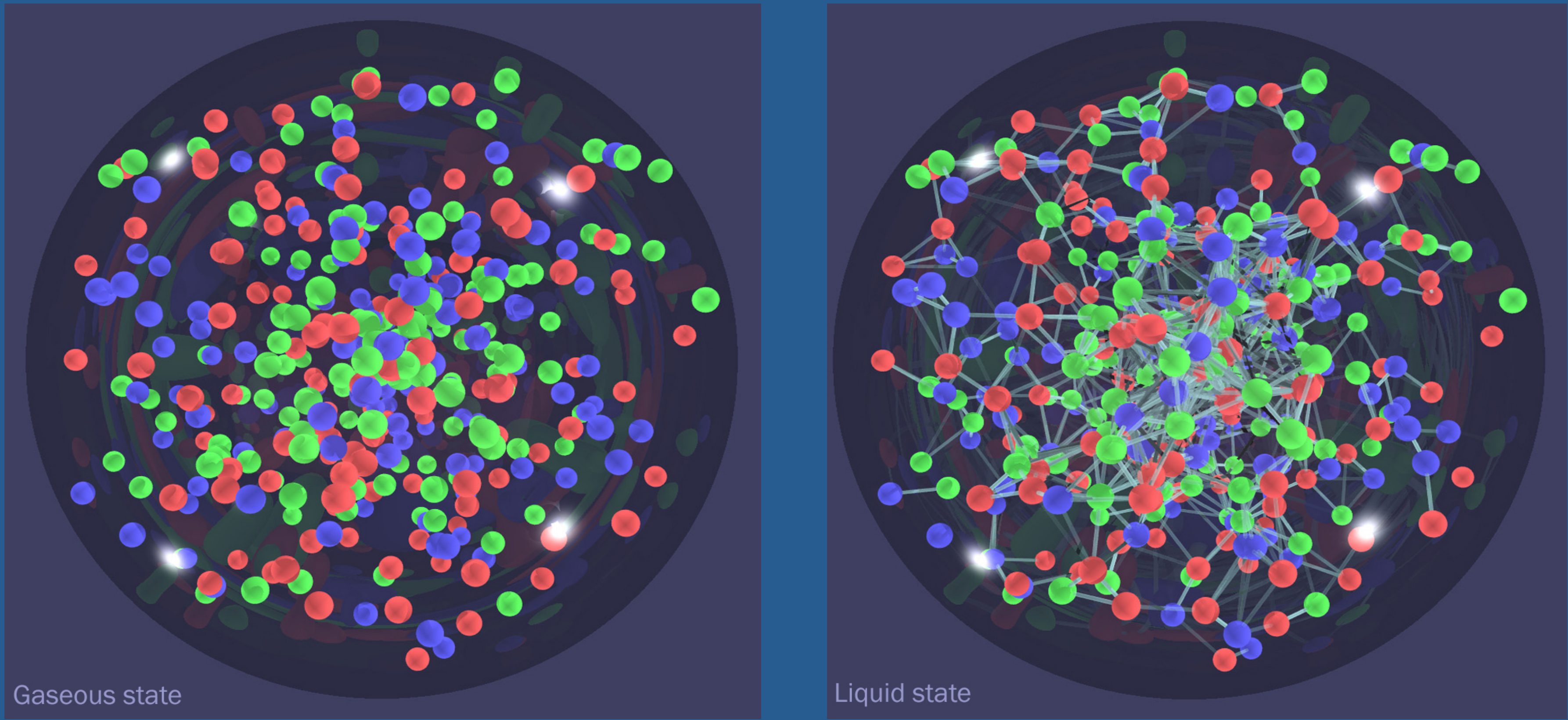
IKF Institut für Kernphysik Frankfurt

ALICE

Introduction


Temperature T [MeV]
200
100
0
1
Nuclei
Net Baryon Density
Early universe
RHIC, LHC
FAIR SIS 300
Quarks and Gluons
Critical point?
Deconfinement and chiral transition
Hadrons
Neutron stars
Color Super-
conductor?


Pb+Pb @ sqrt(s) = 2.76 ATeV
2011-11-12 06:51:12
Fill : 2290
Run : 167693
Event : 0x3d94315a



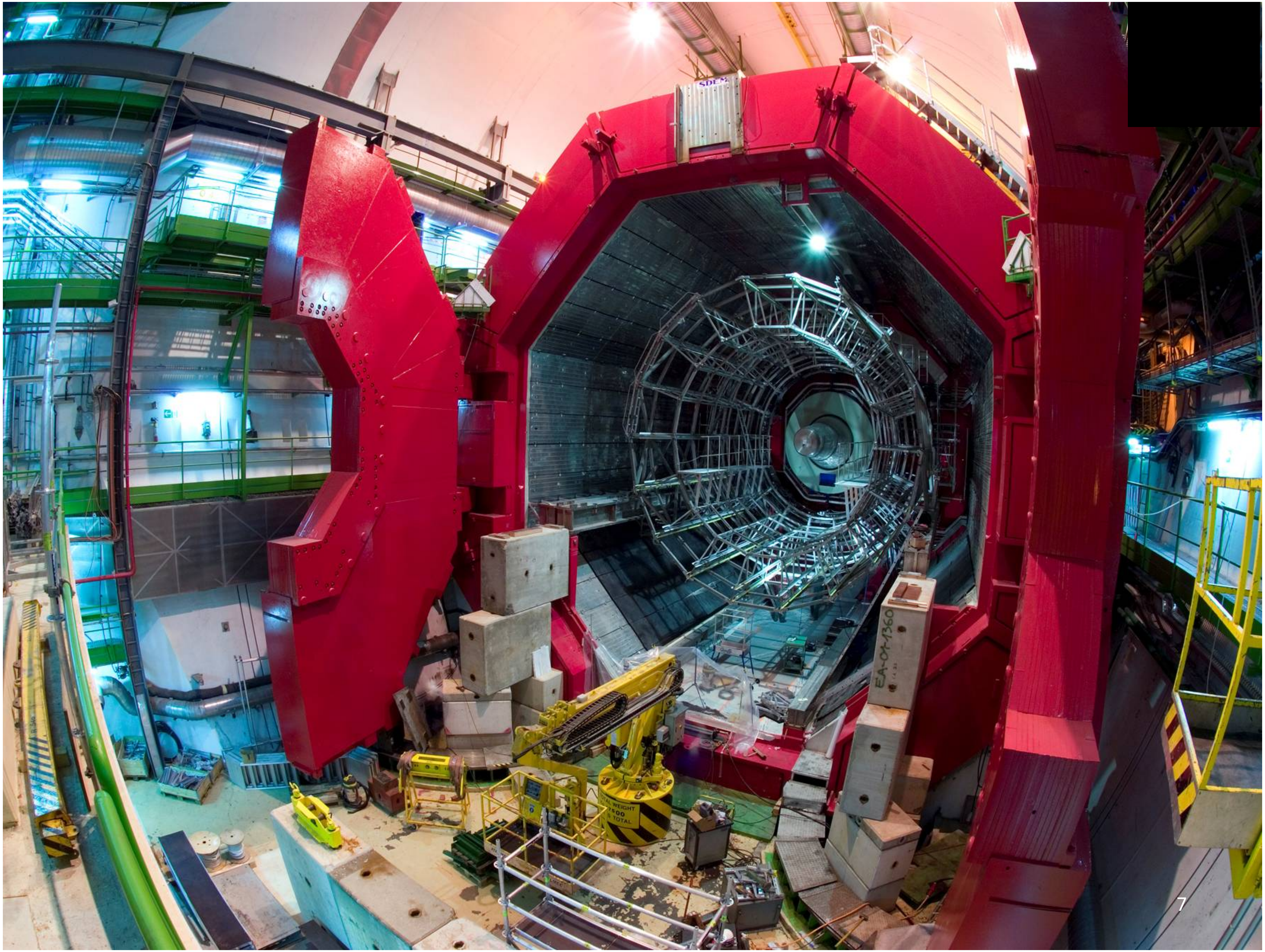
Heavy-ion collisions produce‘quasi-thermal’ QCD matter

Experimental Program

- CERN-SPS (since 1986):
  Heavy ions on *fixed targets*
  $\sqrt{s_{NN}} \approx 20$ GeV
  → 2000: „Discovery of New State of Matter“

- BNL-RHIC (since 2000):
  Heavy-ion collider
  $\sqrt{s_{NN}} = 200$ GeV
  → 2005: „QGP is a strongly coupled liquid“

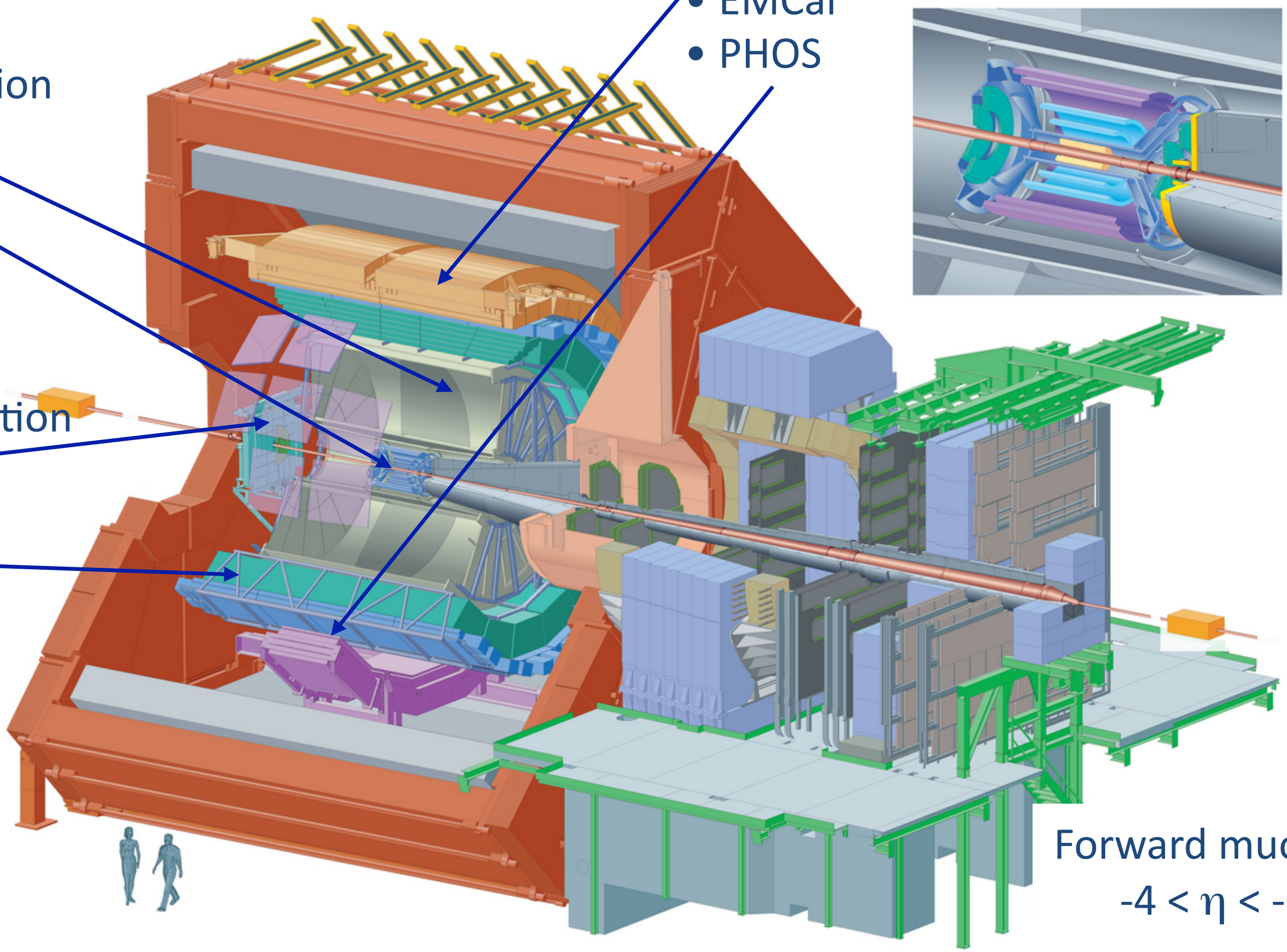
- CERN-LHC (since 2010)
  Heavy-ion collider
  $\sqrt{s_{NN}} = 2.76$ TeV
  → Precise characterization of QGP


SDEM
EA-04-1360

ALICE

Central tracker:
$|\eta| < 0.9$
High resolution
- TPC
- ITS

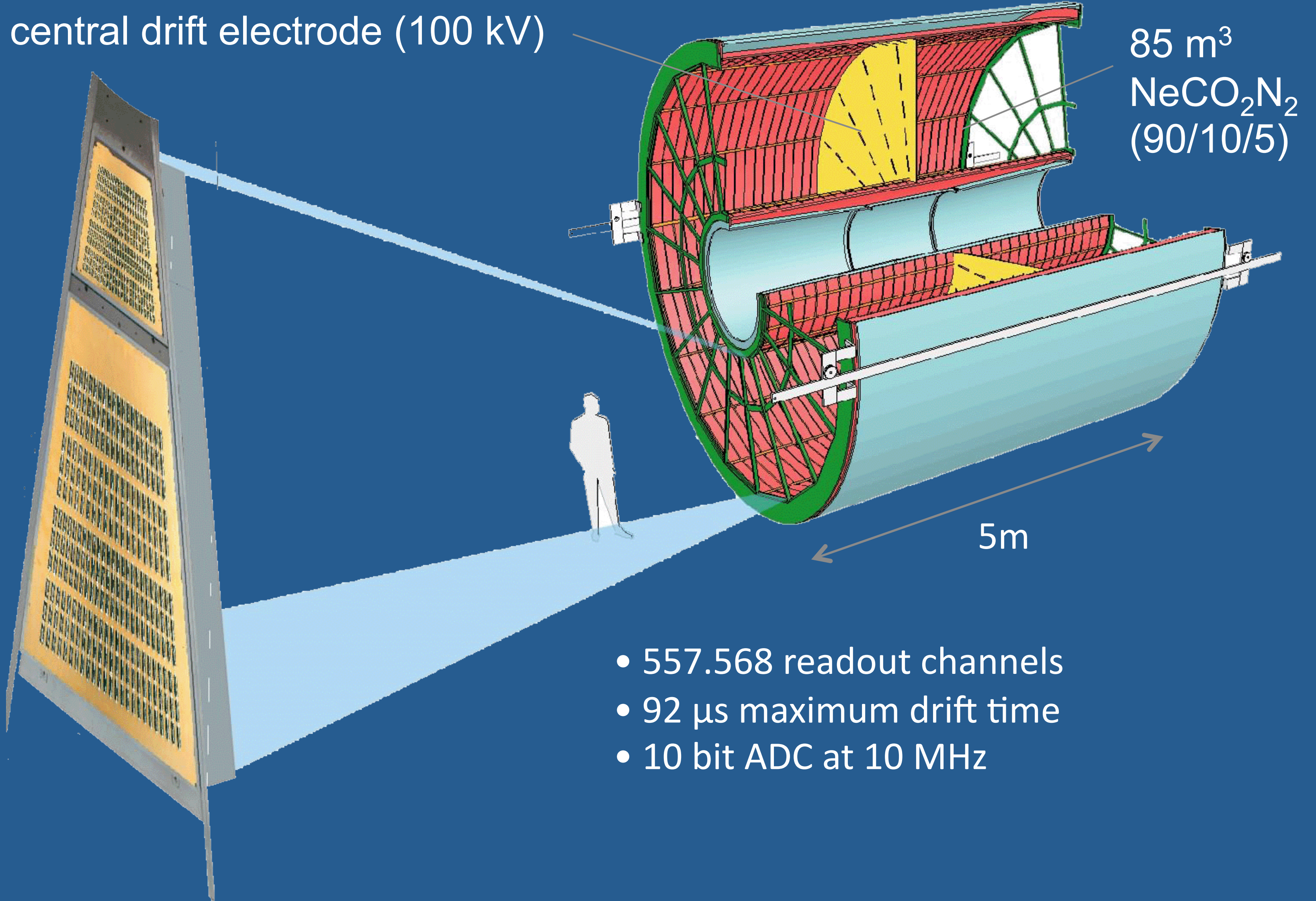
EM Calorimeters
- EMCal
- PHOS



Particle identification
- HMPID
- TRD
- TOF

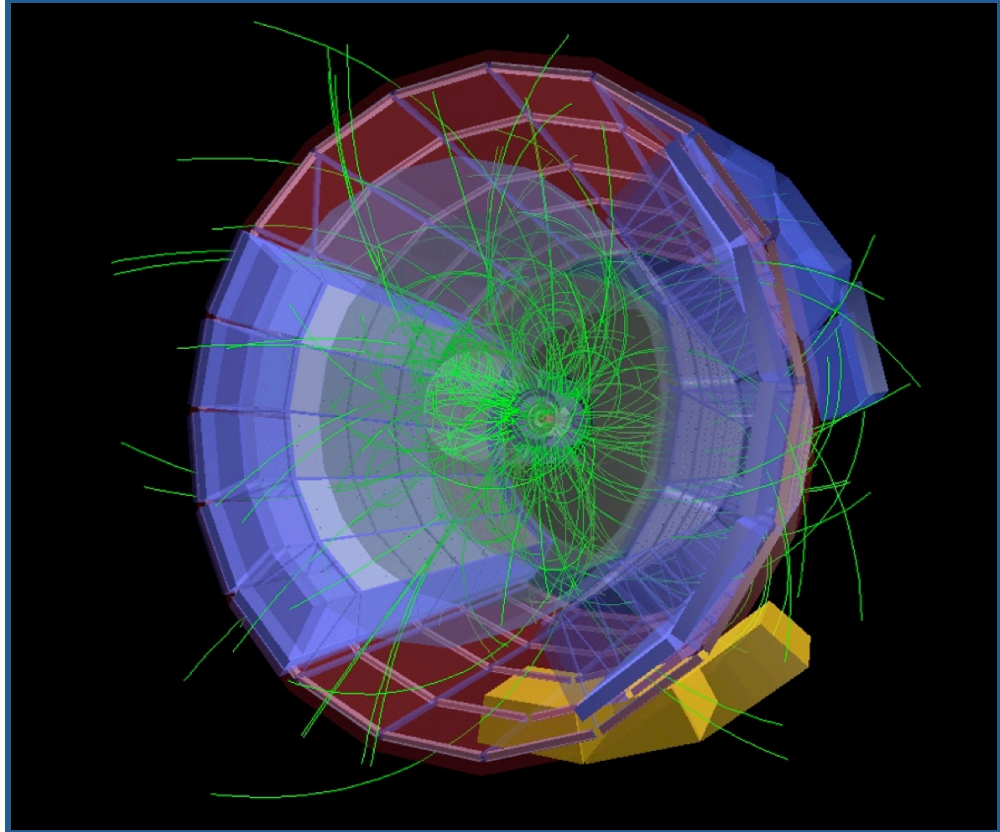
Forward muon arm
$-4 < \eta < -2.5$

Time Projection Chamber TPC



- 557.568 readout channels
- 92 µs maximum drift time
- 10 bit ADC at 10 MHz

ALICE



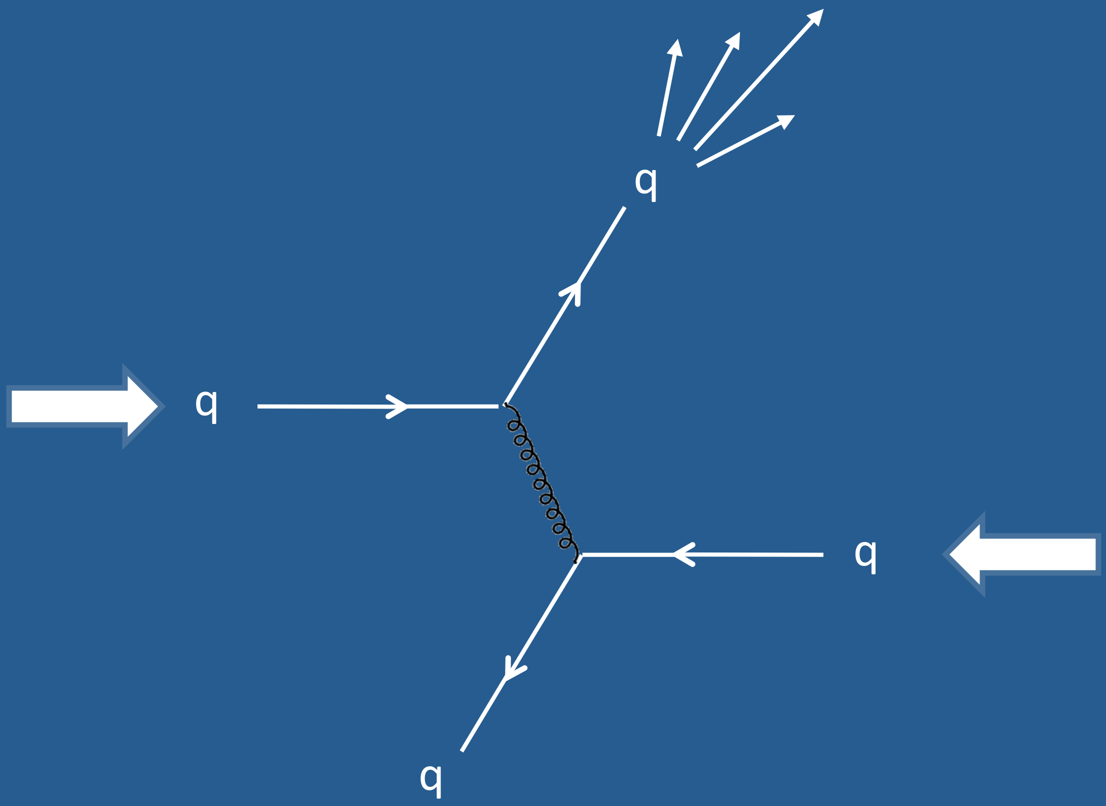
- Tracking and momentum measurement of charged particles: ITS,TPC,TRD
- Hadron PID (p, K, π): ITS, TPC, TOF, HMPID
- Topological reconstruction of secondary decay vertices (Λ, K°, γ, D, B, Λ_c,...): ITS, TPC, TOF, TRD
- Electron ID: ITS, TPC, TRD
- Muon ID: Myon-Arm
- Photon reconstruction: PHOS, EMCAL

Current and Near Future Data Sets

- 2009:
  - pp 900 GeV
- 2010:
  - pp 7 TeV
  - pp 900 GeV
  - Pb-Pb 2.76 TeV
- 2011:
  - pp 2.76 TeV
  - pp 7 TeV
  - Pb-Pb 2.76 TeV
- 2012:
  - p-Pb 4.4 TeV

High p_T

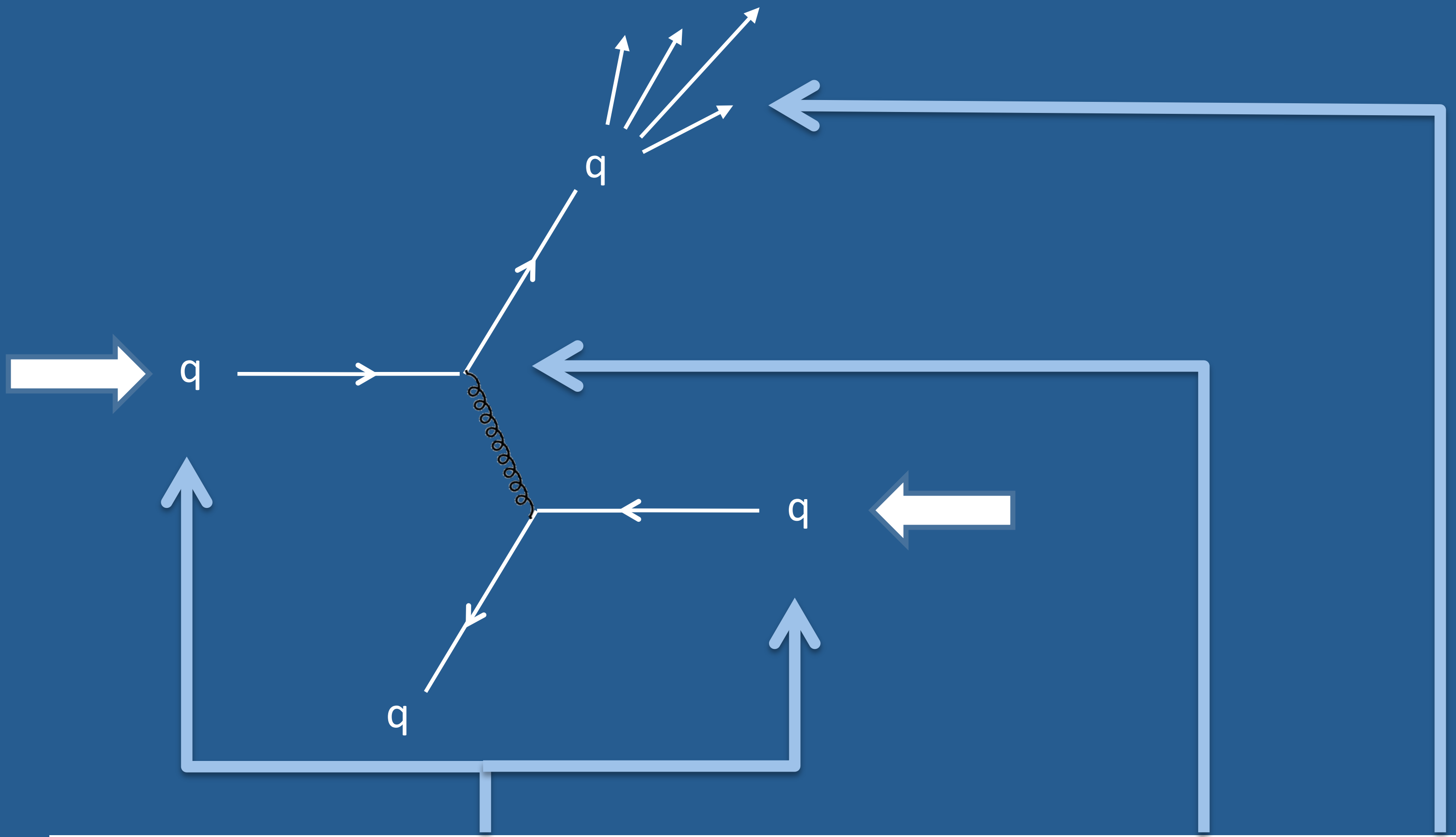
Particle Production in pp



Vacuum:
„hard“ scattering of partons (q,g) from incoming nucleons

fragmentation into „jets“ of hadrons

Particle Production in pp



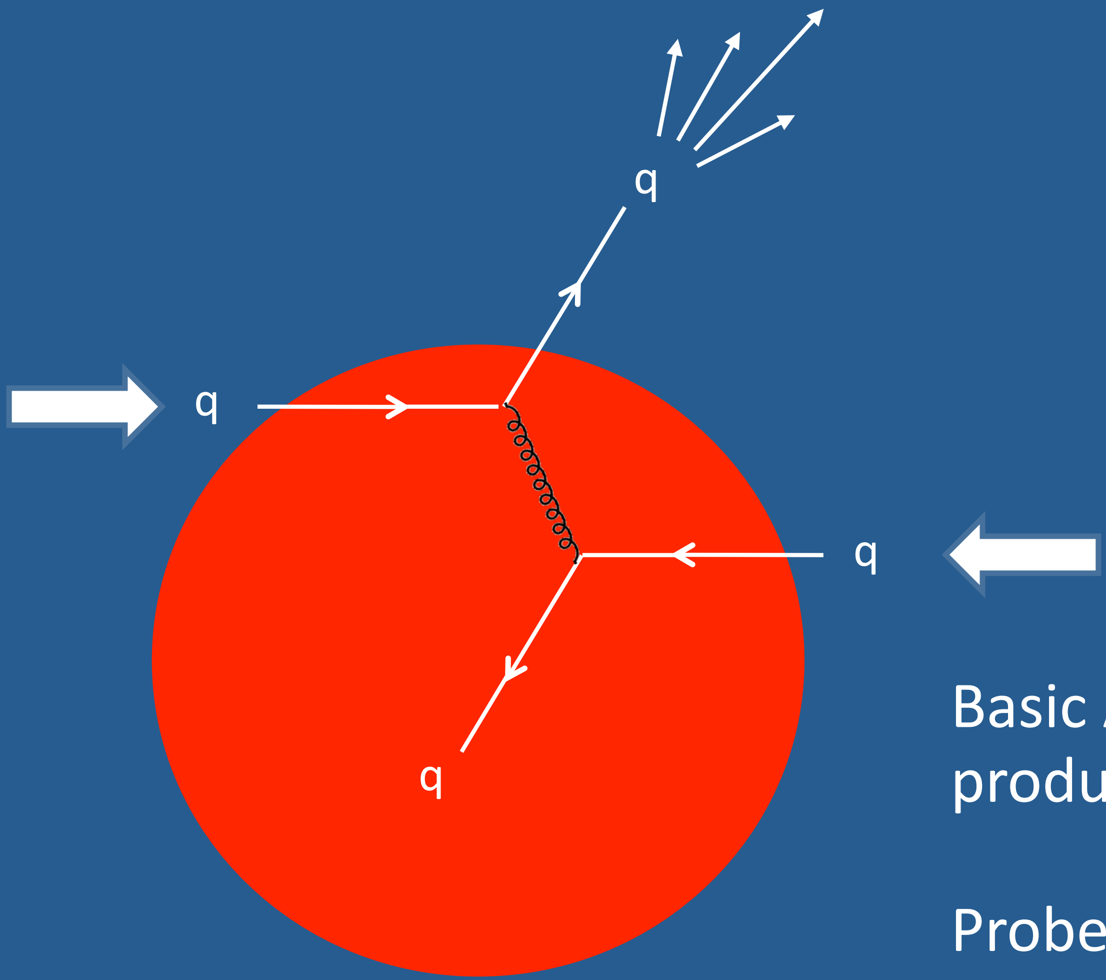
$$\frac{d^2\sigma^h}{dy\,d^2p_T} = \int dx_a dx_b\, G_a(x_a,\mu_f)\,G_b(x_b,\mu_f)\,\frac{d\sigma_{ab\to cX}(\mu_R,\mu_f,\mu'_f,x_aP,x_bP,p_T/z)}{d\hat{t}}\,\frac{D_c^h(z,\mu'_f)}{\pi z} + \mathcal{O}\left(\frac{\Lambda^2}{Q^2}\right)$$

Parton Distribution Function (PDF)

elementary cross section (perturbative)

fragmentation Function

Particle Production in Heavy Ion

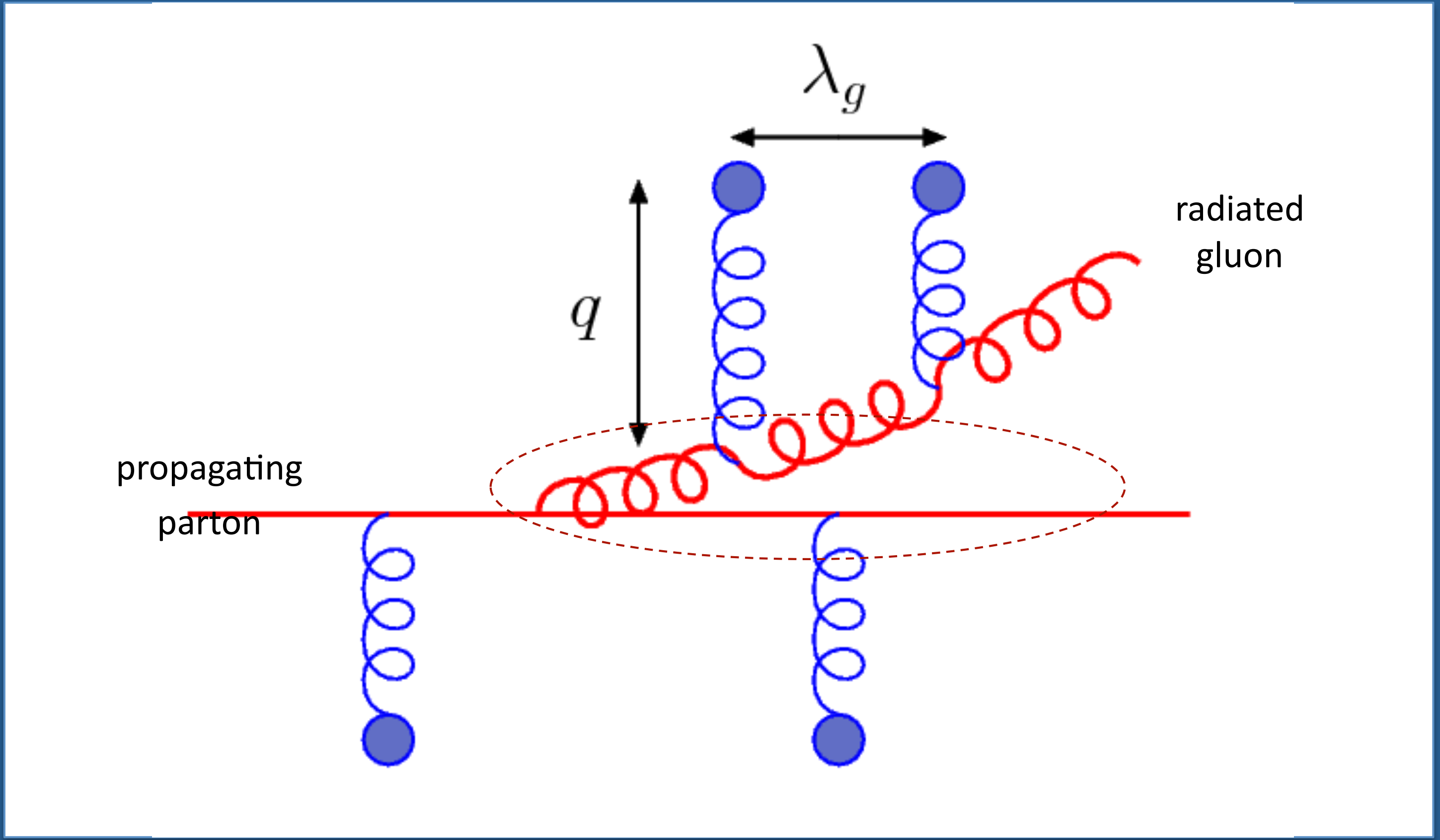


Basic Assumption: Initial-state production known from pQCD

Probe medium through energy loss

Sensitive to medium density, transport properties

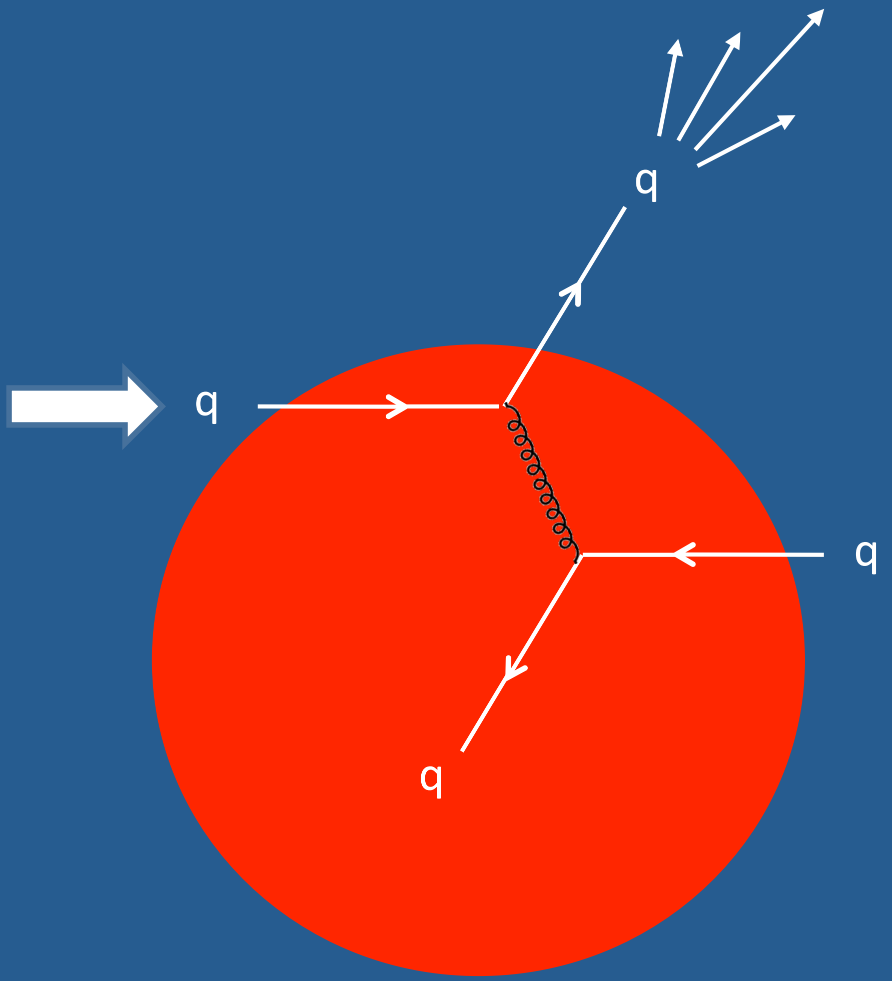
Medium-Induced Radiation



$$\Delta E_{med} \sim \alpha_S \hat{q} L^2$$

$\Delta E_{gluon} > \Delta E_{u,d} > \Delta E_c > \Delta E_b$ *Identified Particles*

Not really like X-Ray



Interaction with medium not known
(to be understood)

Parton momentum not known

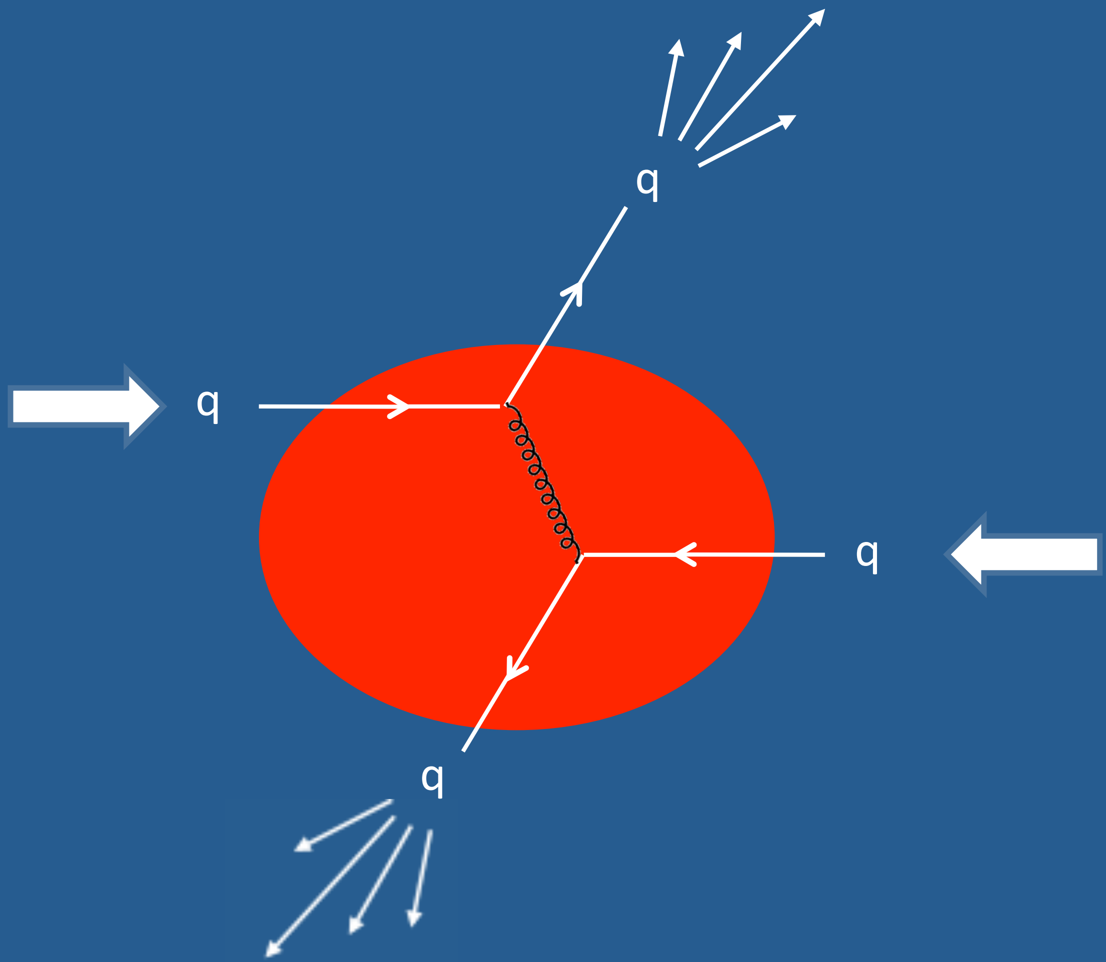
Parton position not known
(only probablility)

Medium not static

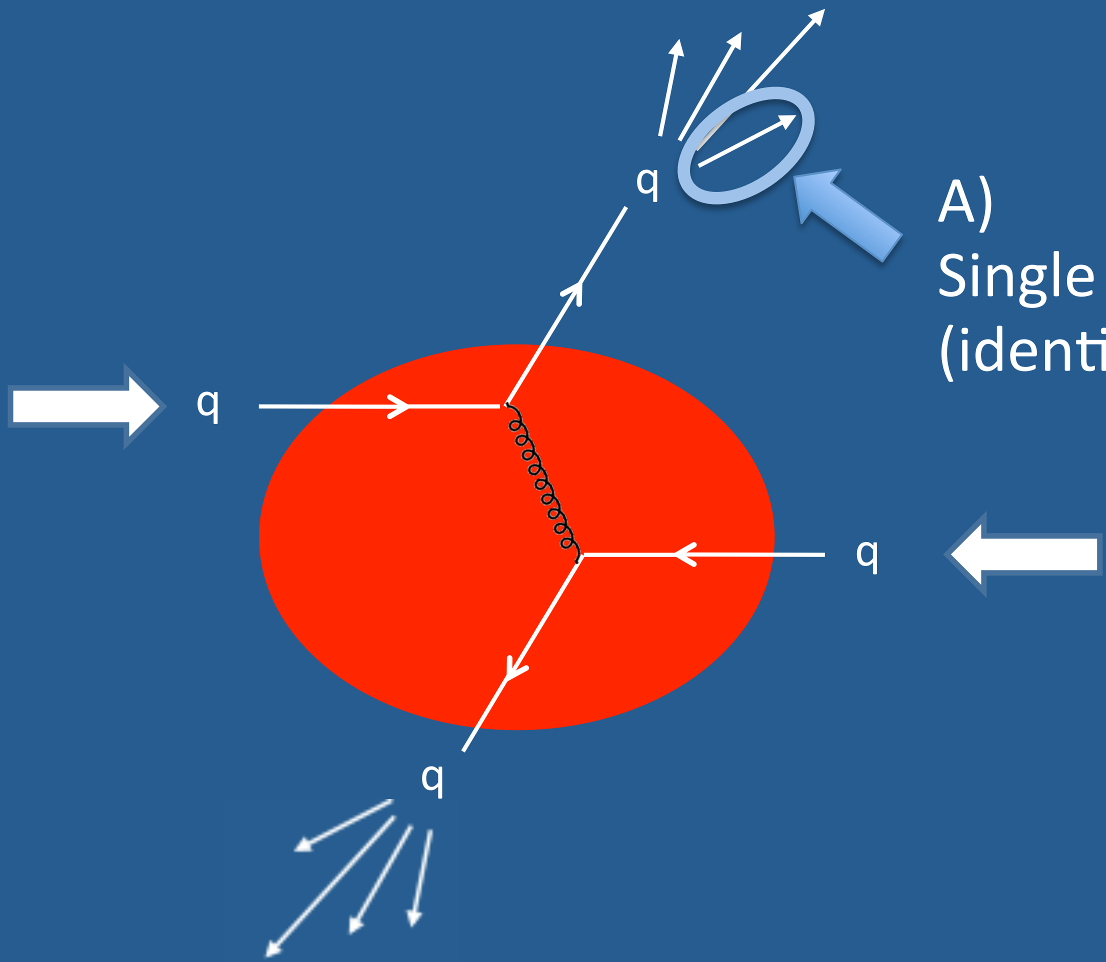
For theoretical understanding:
Study system systematically

For experiment:
High p_T = High rates necessary

Systematic Studies

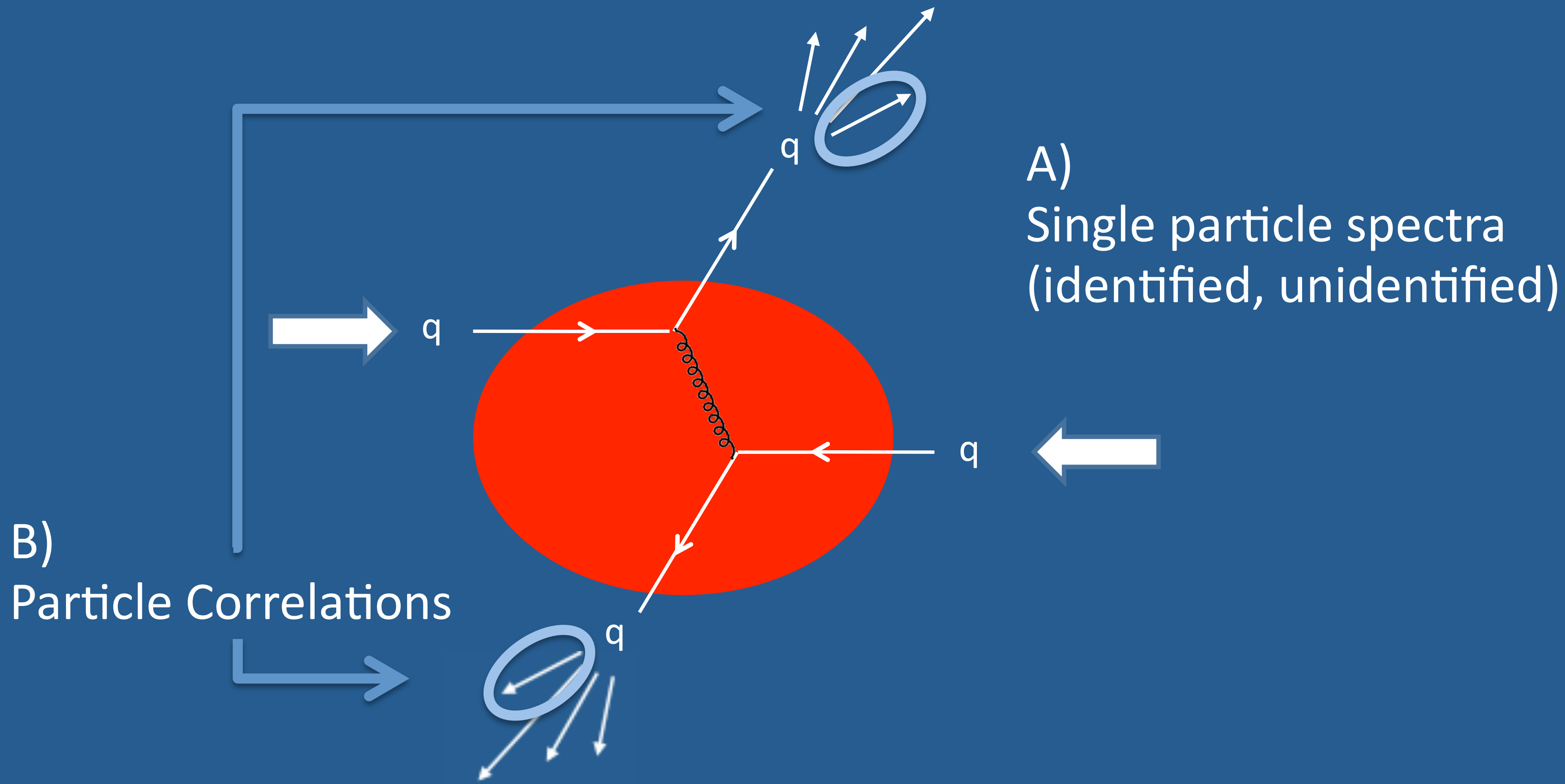


Systematic Studies

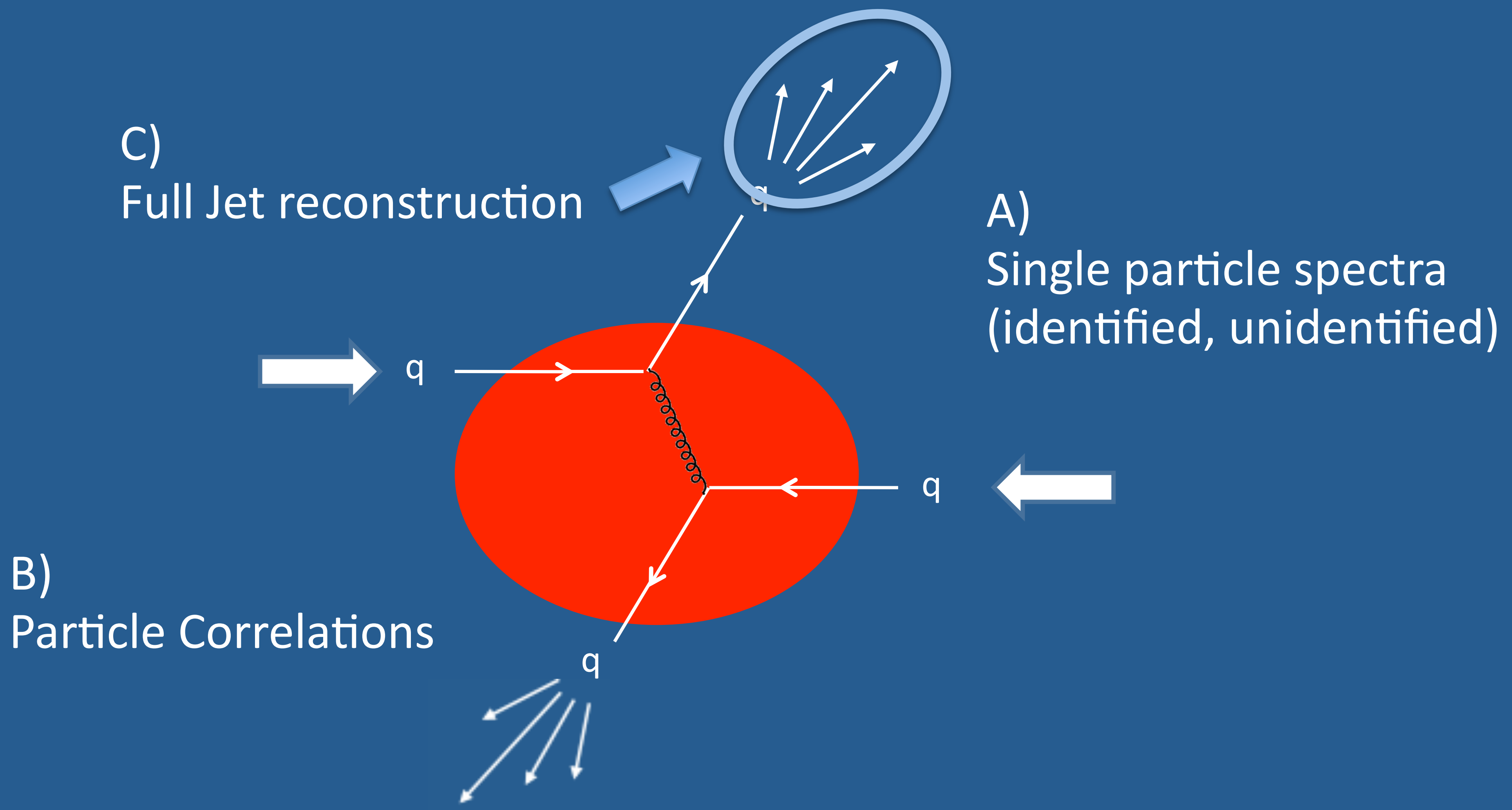


A)
Single particle spectra
(identified, unidentified)

Systematic Studies



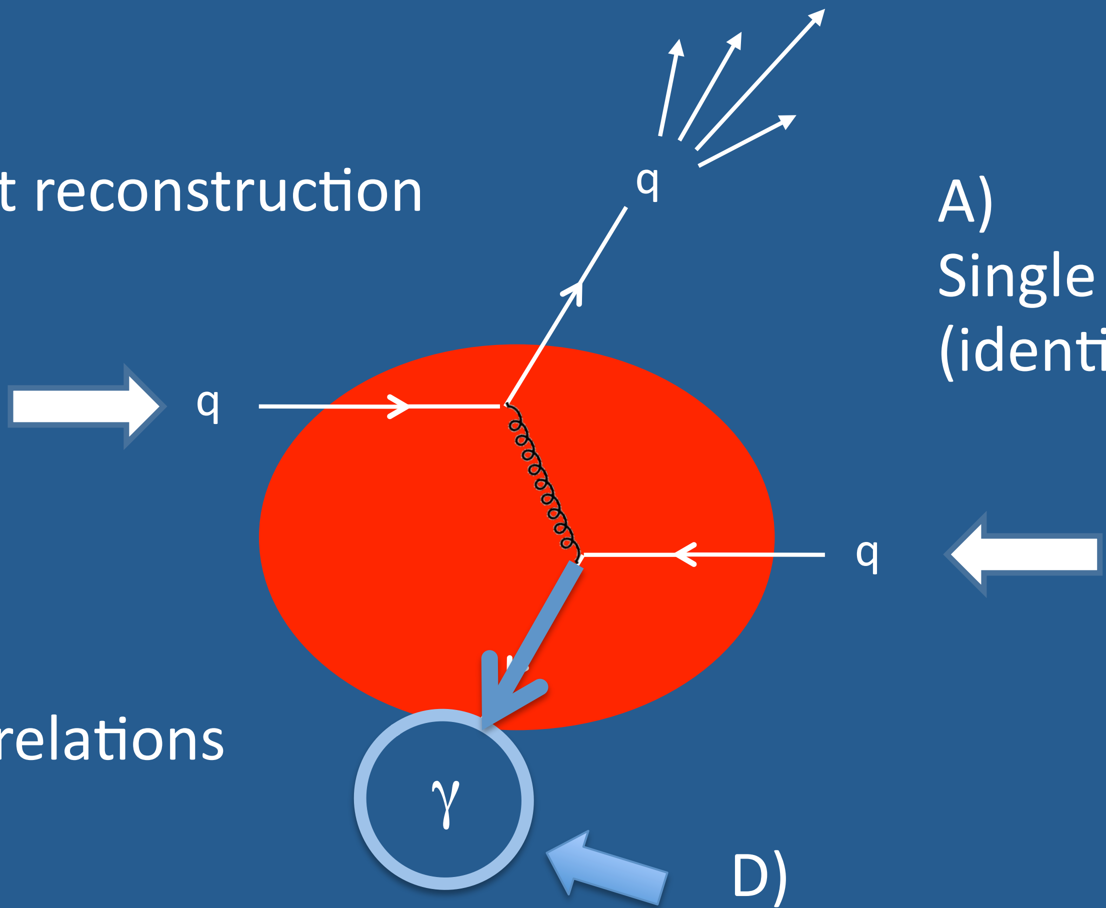
Systematic Studies



Systematic Studies

C)
Full Jet reconstruction

A)
Single particle spectra
(identified, unidentified)

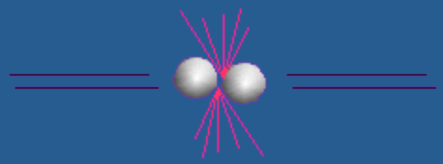


B)
Particle correlations

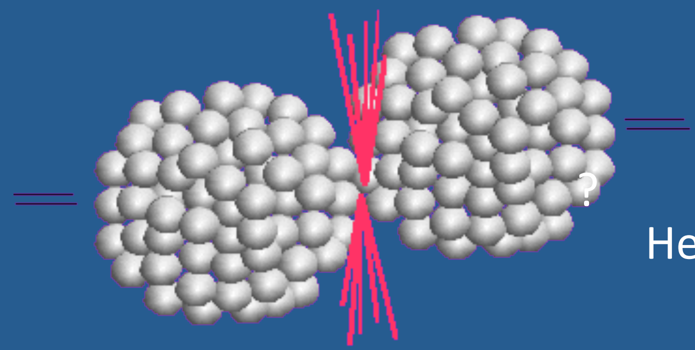
D)
Photon tagged jets

Single Particle Production

Compare Heavy Ion and pp



$\times N_{Coll} =$



Heavy Ion

- N_{coll}:Number of collisions

Nuclear Modification Factor: R_{AA}

Number of particles in HI

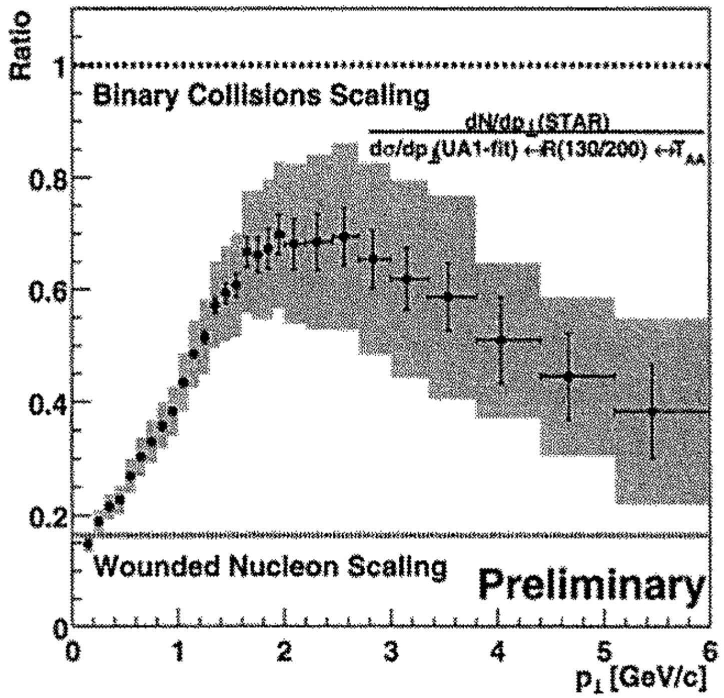
$$R_{AA} = \frac{1/N_{AA}^{evt} \cdot d^2N_{AA}/dp_T d\eta}{\langle N_{coll} \rangle \cdot d^2N_{pp}/dp_T d\eta}$$

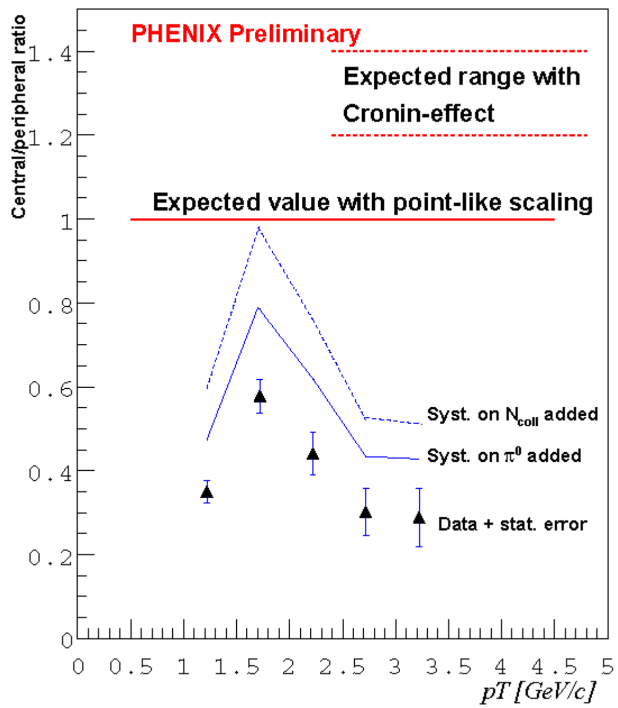
Number of collisions from Glauber calculations

Number of particles in pp

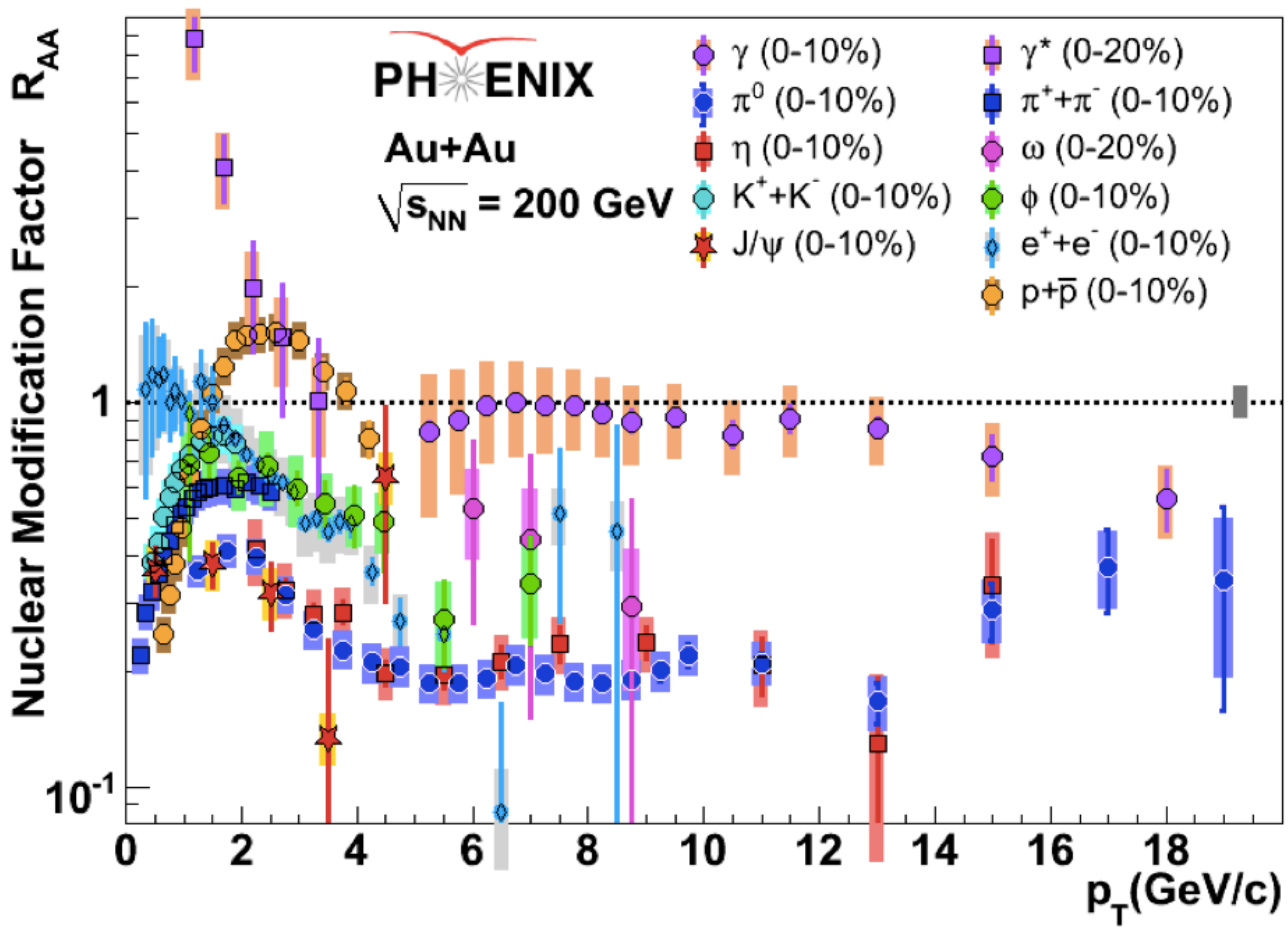
A Discovery at RHIC

Au-Au at $\sqrt{s_{NN}}$ = 200 GeV



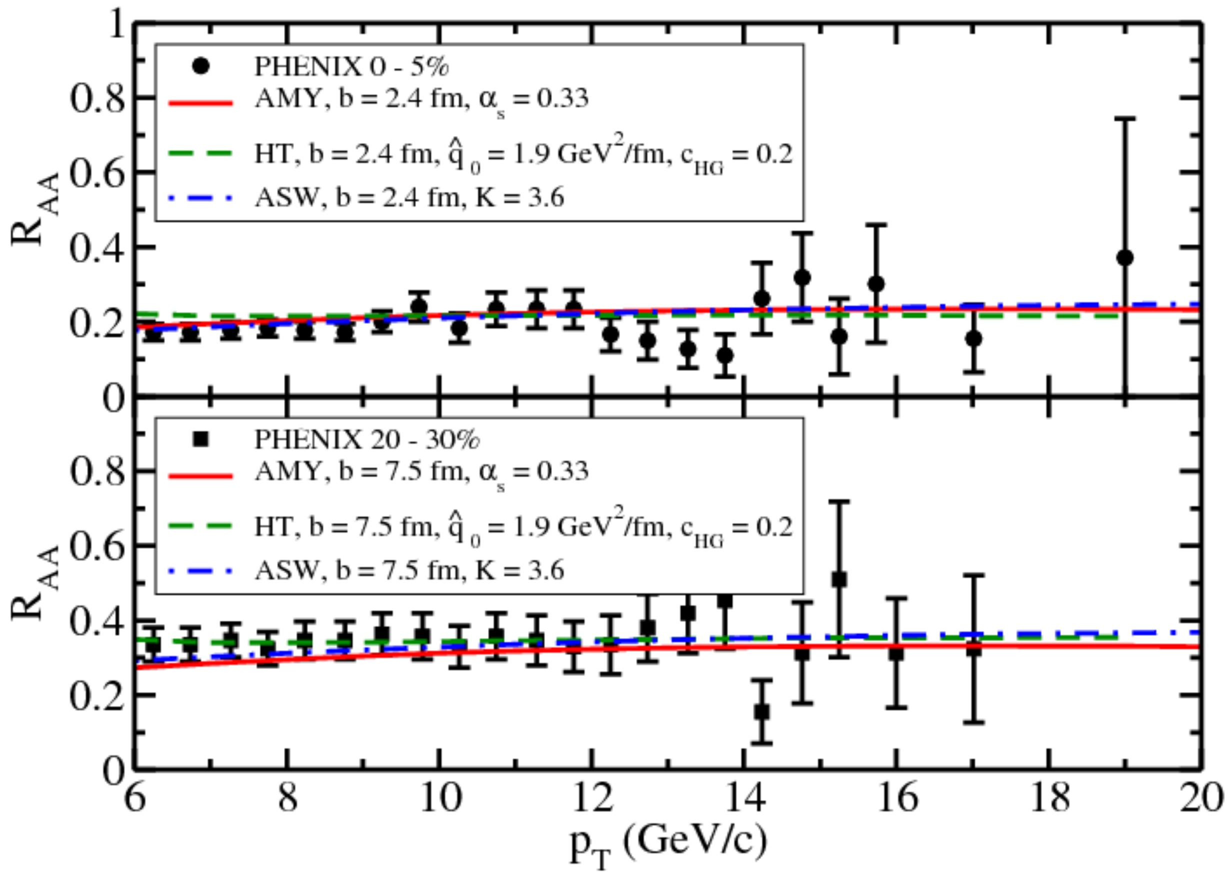


R_{AA} at RHIC



PHENIX
Au+Au
$\sqrt{s_{NN}}$ = 200 GeV
γ (0-10%)
π⁰ (0-10%)
η (0-10%)
K⁺+K⁻ (0-10%)
J/ψ (0-10%)
γ* (0-20%)
π⁺+π⁻ (0-10%)
ω (0-20%)
φ (0-10%)
e⁺+e⁻ (0-10%)
p+p̄ (0-10%)
Nuclear Modification Factor R_AA
p_T(GeV/c)

R_{AA} at RHIC



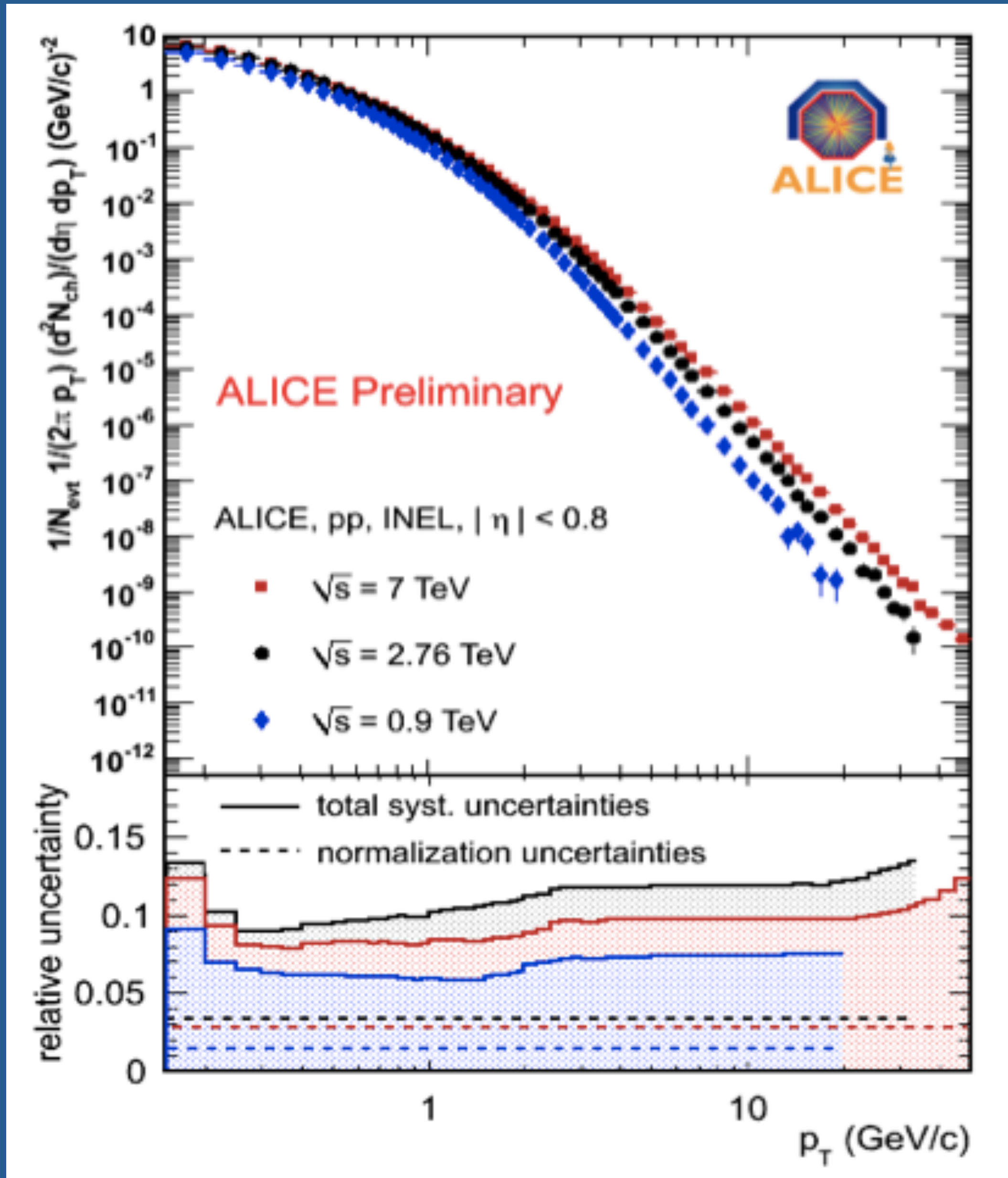
reasonably well described by theory..

precise determination of medium properties not yet possible

not constraining enough on models

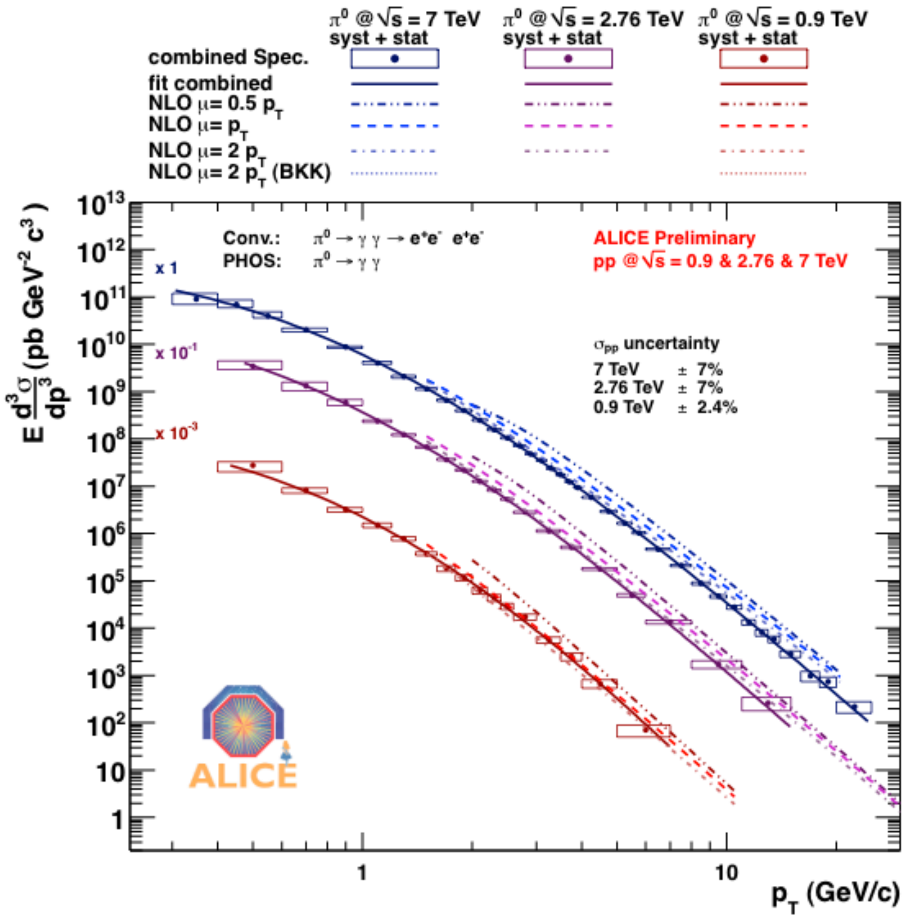
Single Particles at LHC

Charged Hadron p_T Spectra

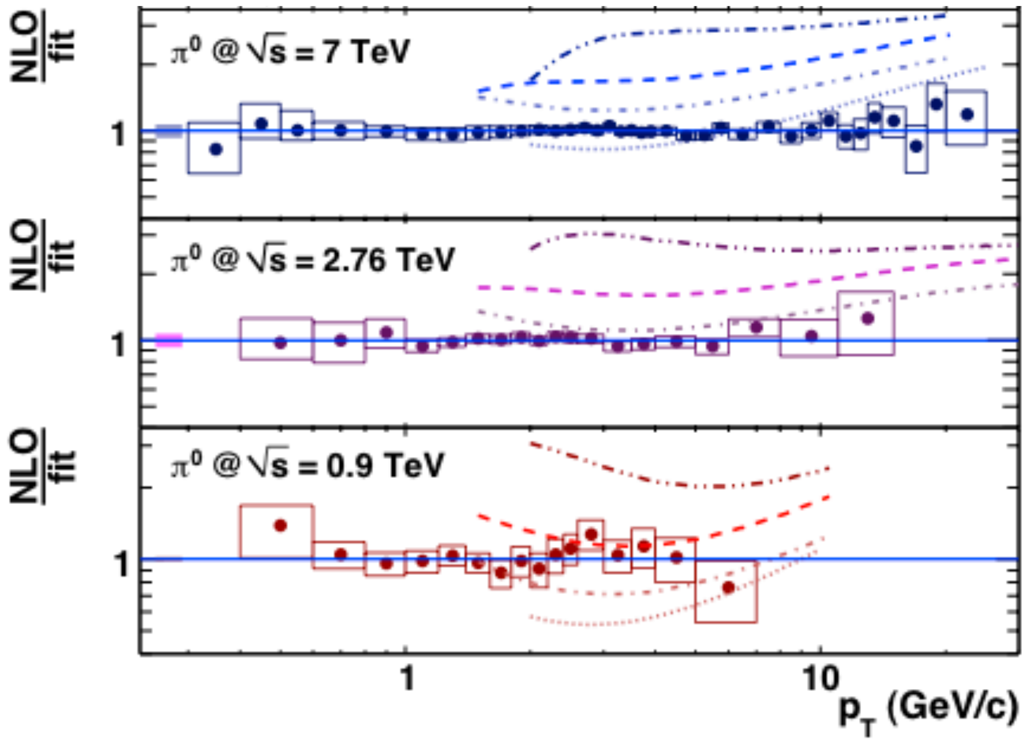


p+p

Neutral Pion p_T Spectra



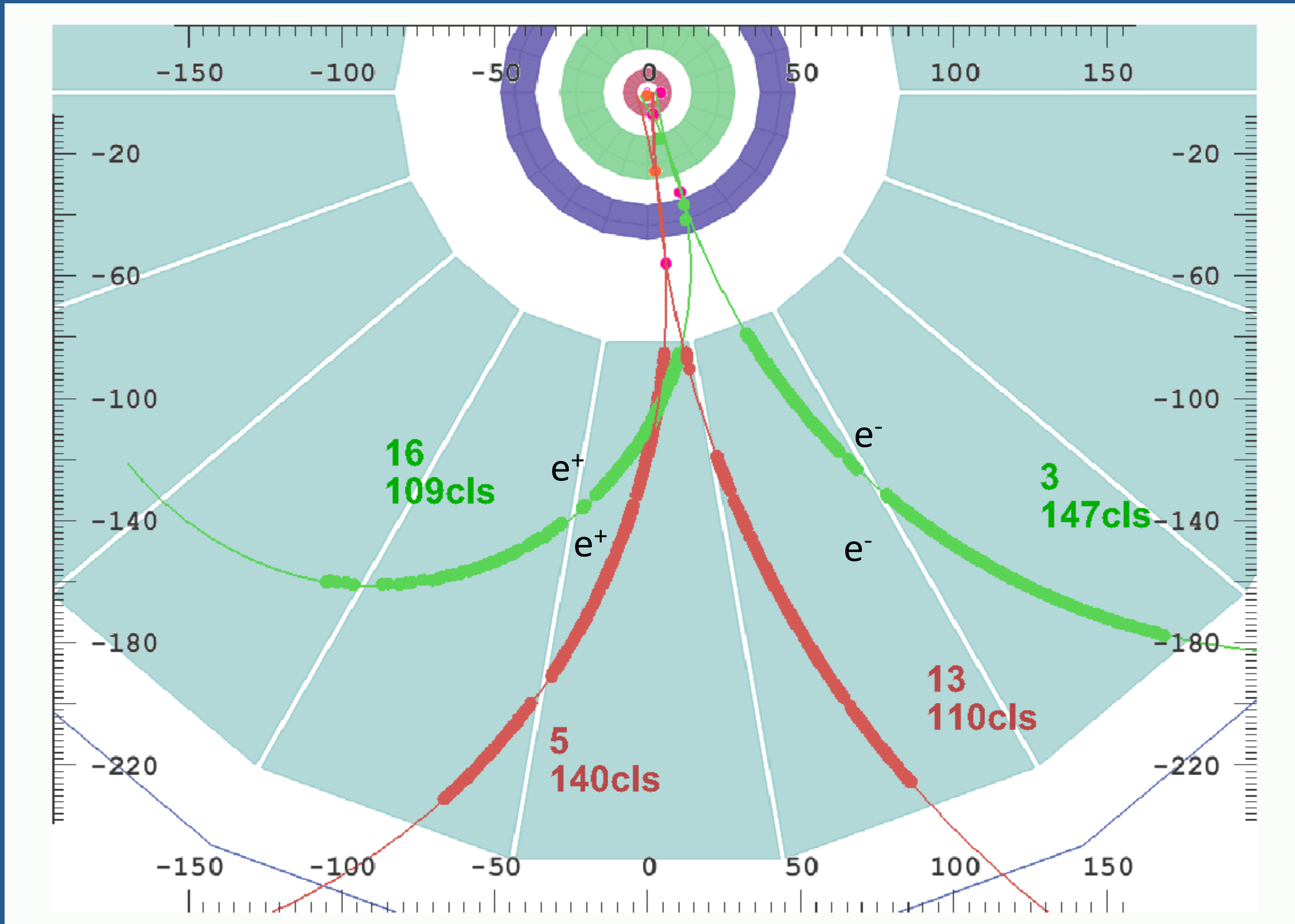
NLO pQCD (W. Vogelsang):
PDF: CTEQ6M5, FF: DSS, scales, $\mu = 0.5\ p_T$, p_T, $2\ p_T$
Also: INCNLO with BKK FF



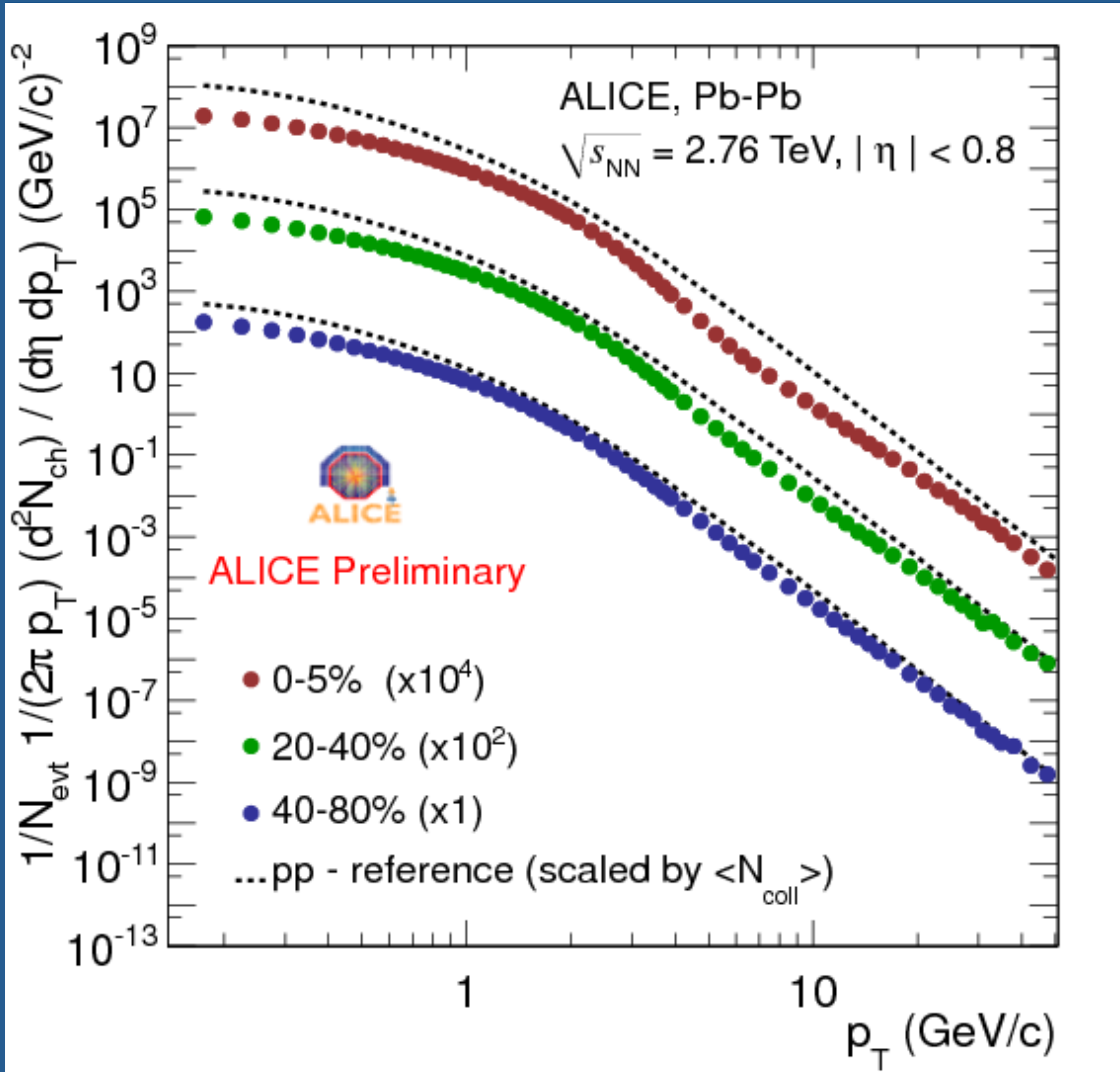
- NLO pQCD with DSS FF describes 0.9 TeV data, but overestimates cross sections at 2.76 TeV and 7 TeV for all scales
- Better agreement with 7 TeV data with BKK FF

p+p

Insert: Neutral Pions by Conversion



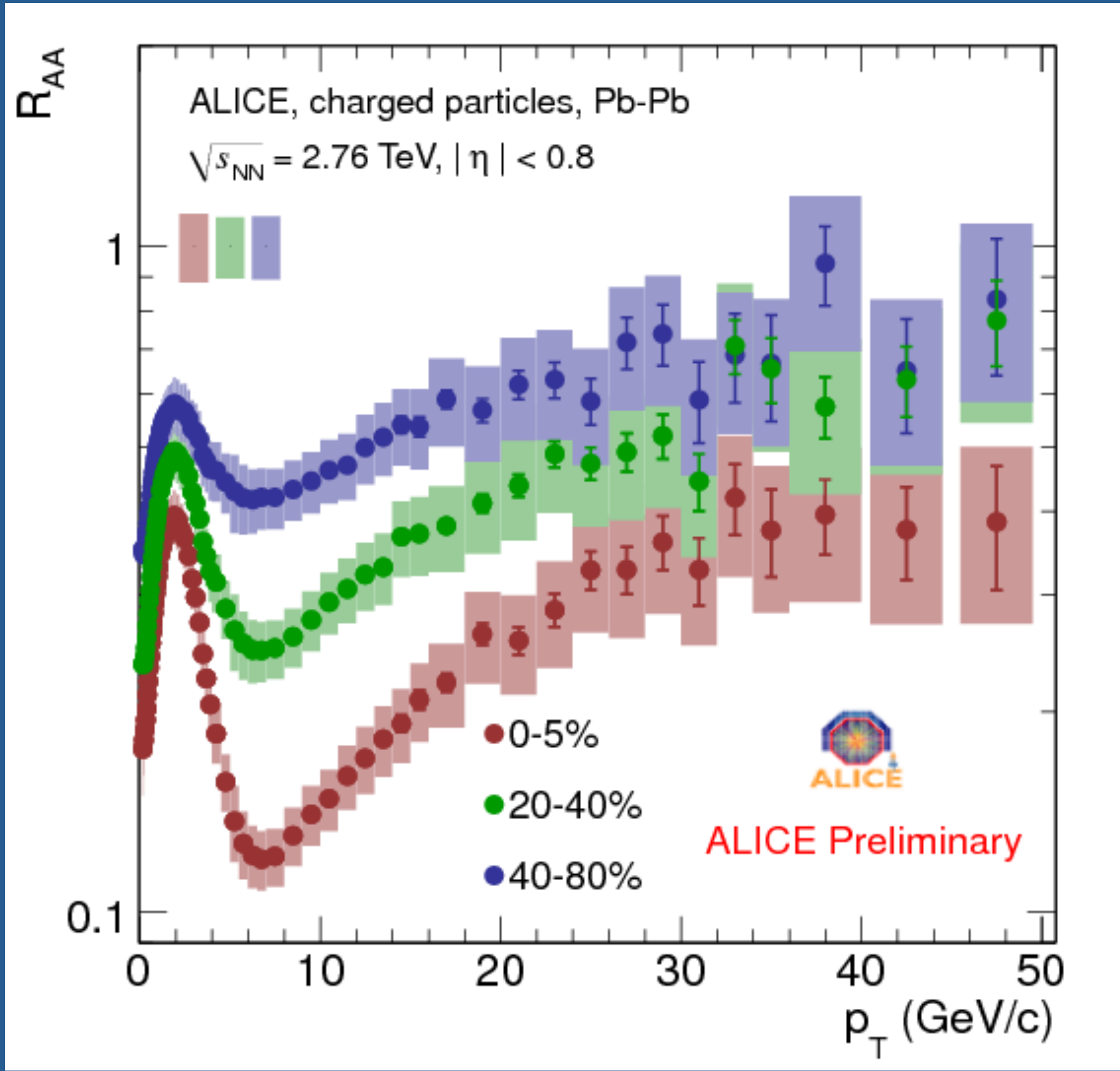
Charged Hadron p_T Spectra



Pb-Pb

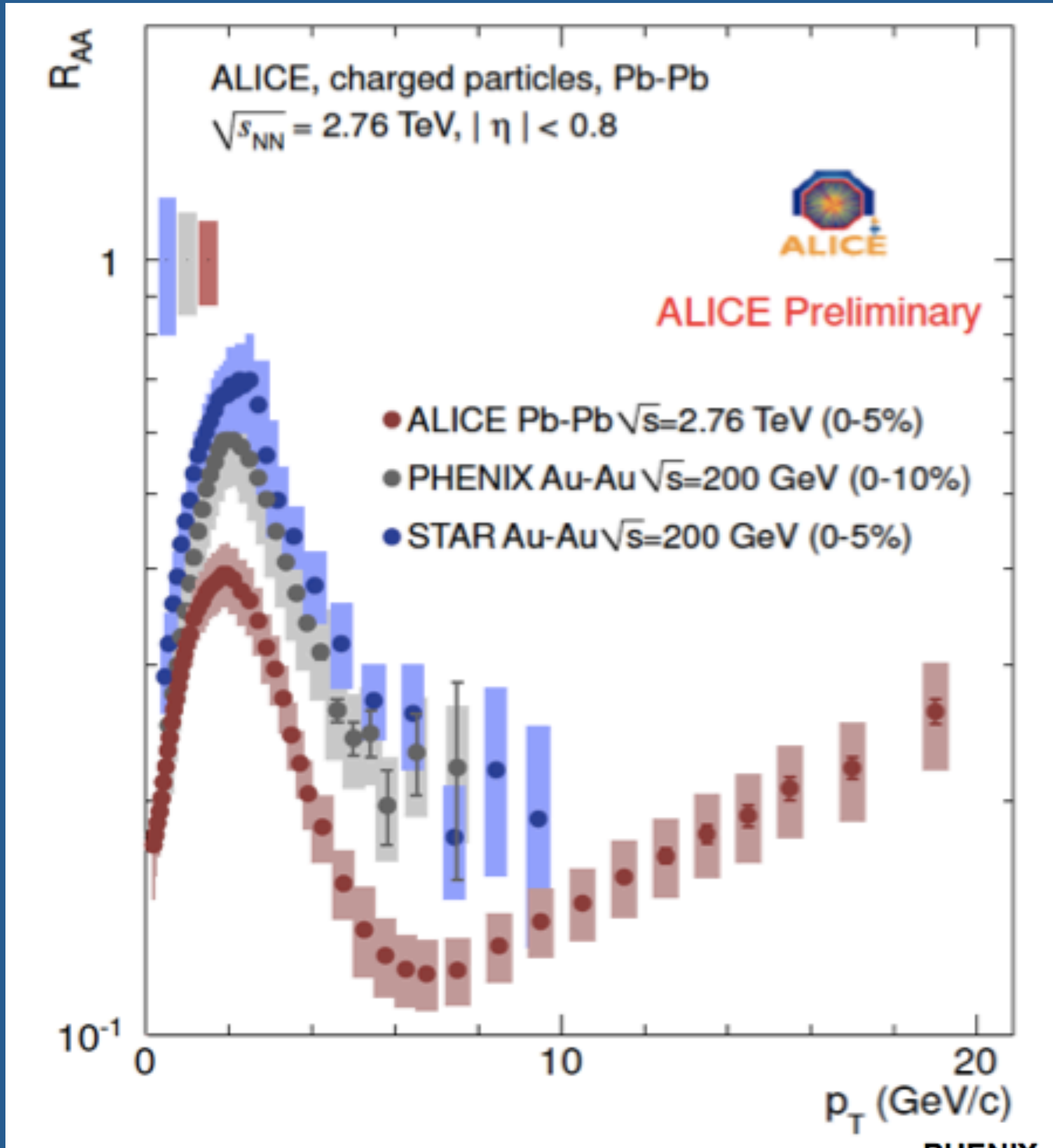
Shape of spectra in Pb-Pb differs strongly from p+p

Nuclear Modification Factor



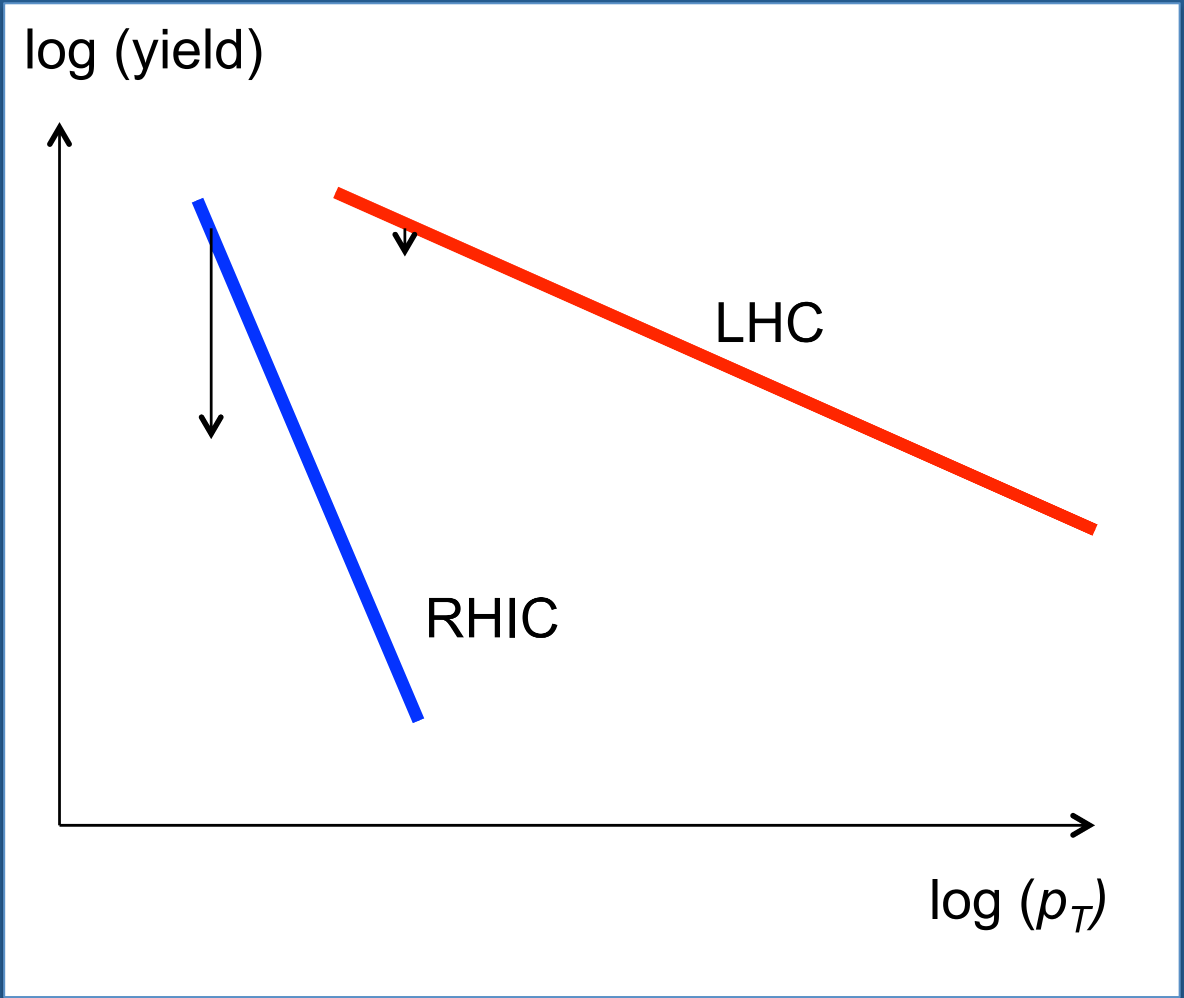
Large suppression R_{AA} rises with p_T

Comparing to RHIC



PHENIX, Phys. Rev. C 69 (2004) 034910.
STAR, Phys. Rev. Lett. 91 (2003) 172302.

R_{AA} Schematics



constant relative energy loss
ΔE/E(√s):
Stronger suppression if
Spectrum is **soft** (RHIC)

→ Observations indicate significantly larger energy loss at the LHC (higher density, lifetime, etc.)

→ rise of $R_{AA}(p_T)$ at high LHC: relative energy loss decreases with p_T

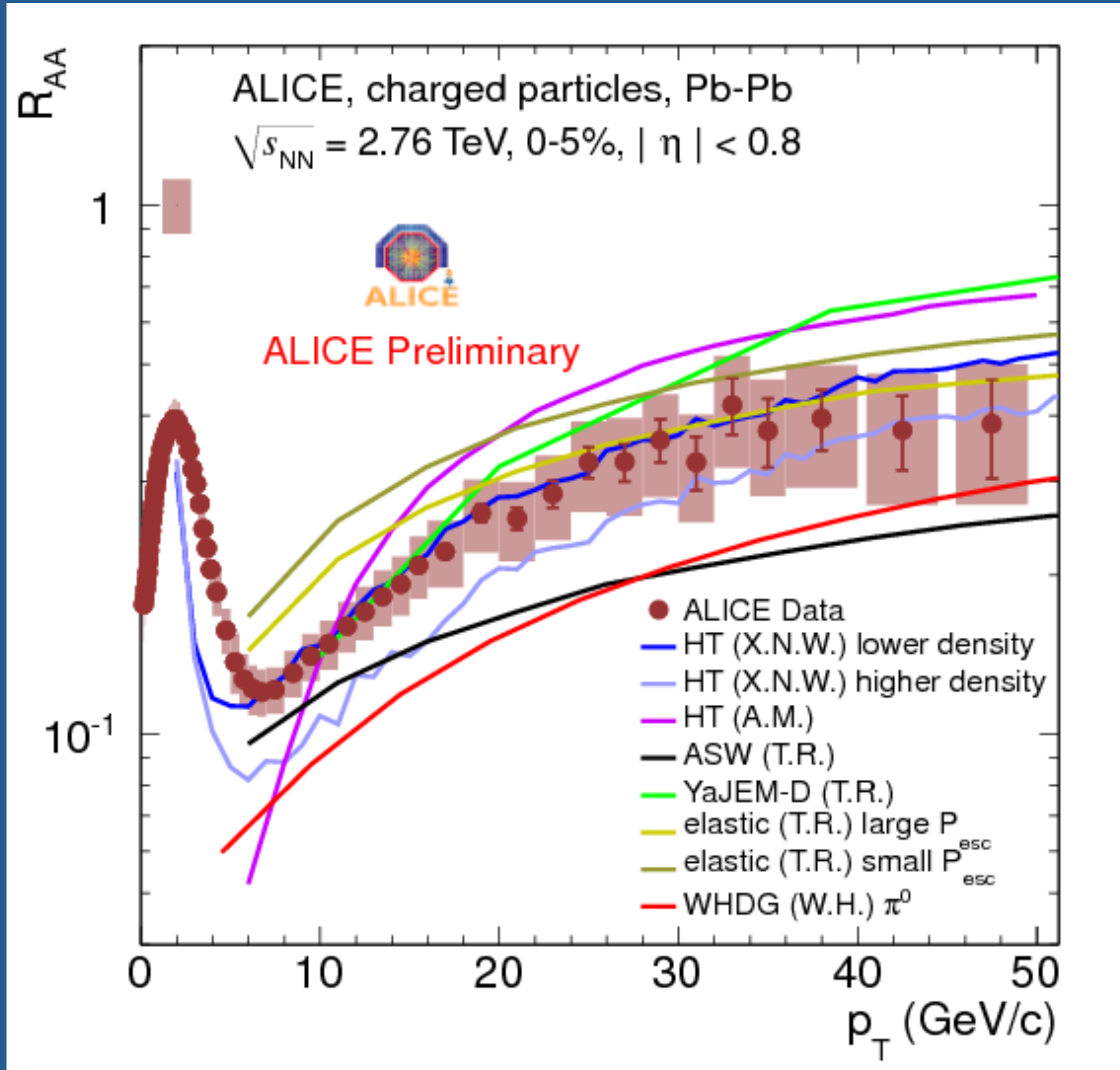
Comparing to Theory

Many Predictions

Ingredients:
- pQCD production
- Medium density profile tuned to RHIC data, scaled
- Energy loss model

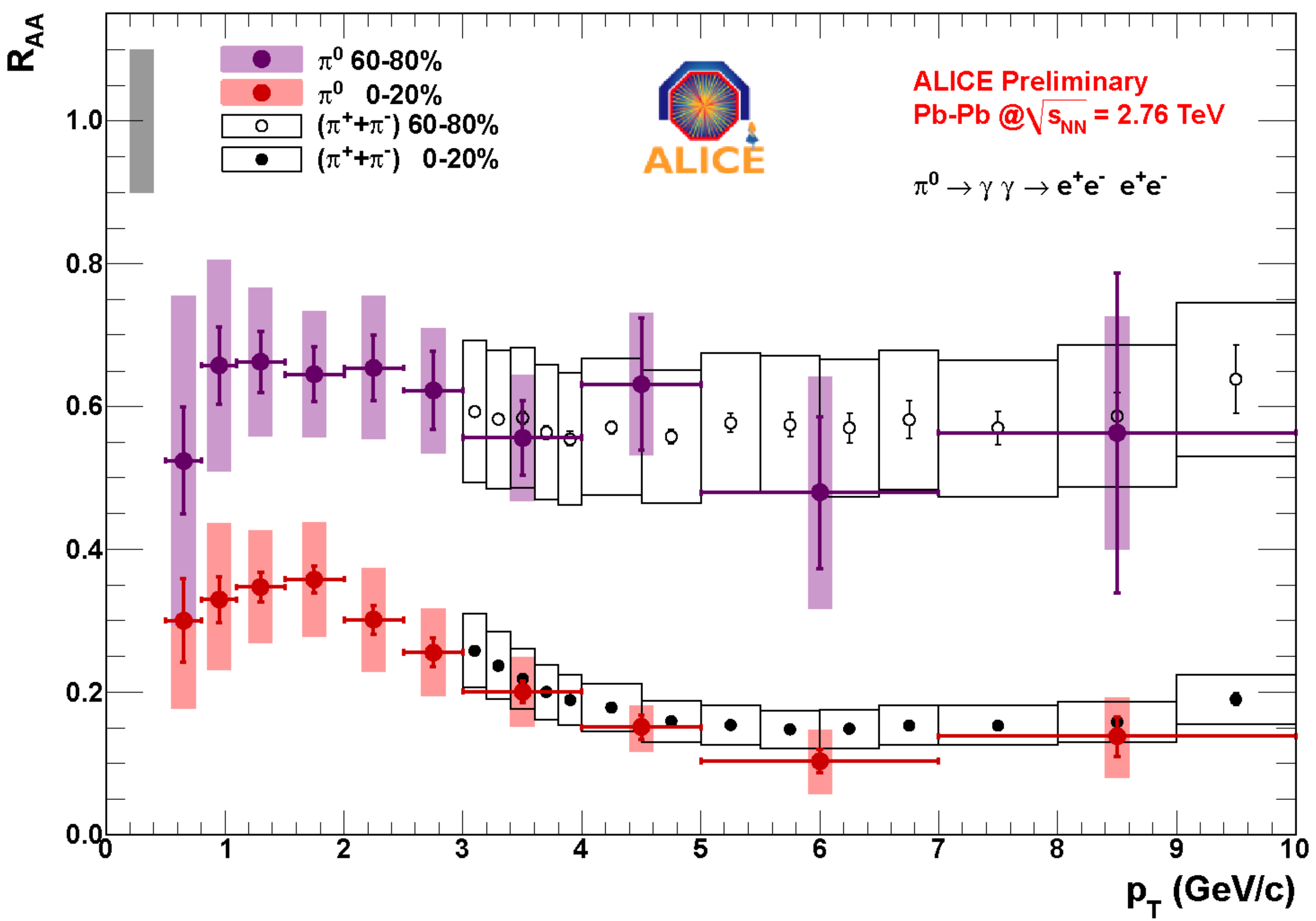
Variety of results

Needs careful review



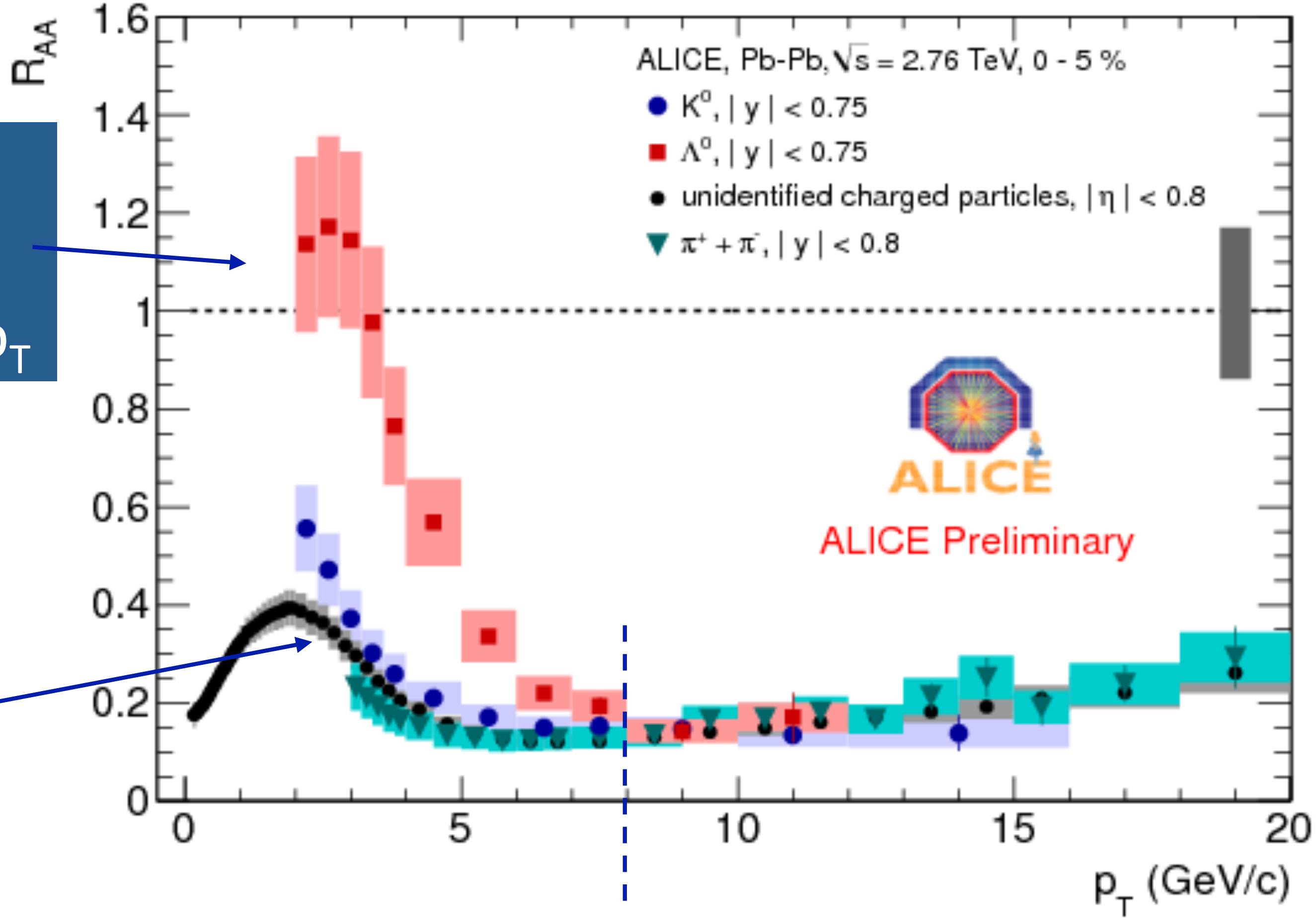
All calculations show increase with p_T

Identified R_{AA} - π^0, $\pi^+ + \pi$



Identified R_{AA} - strangeness

Λ: R_{AA}~1 at pT~3 GeV
Smaller suppression,
Λ/K enhanced at low p_T

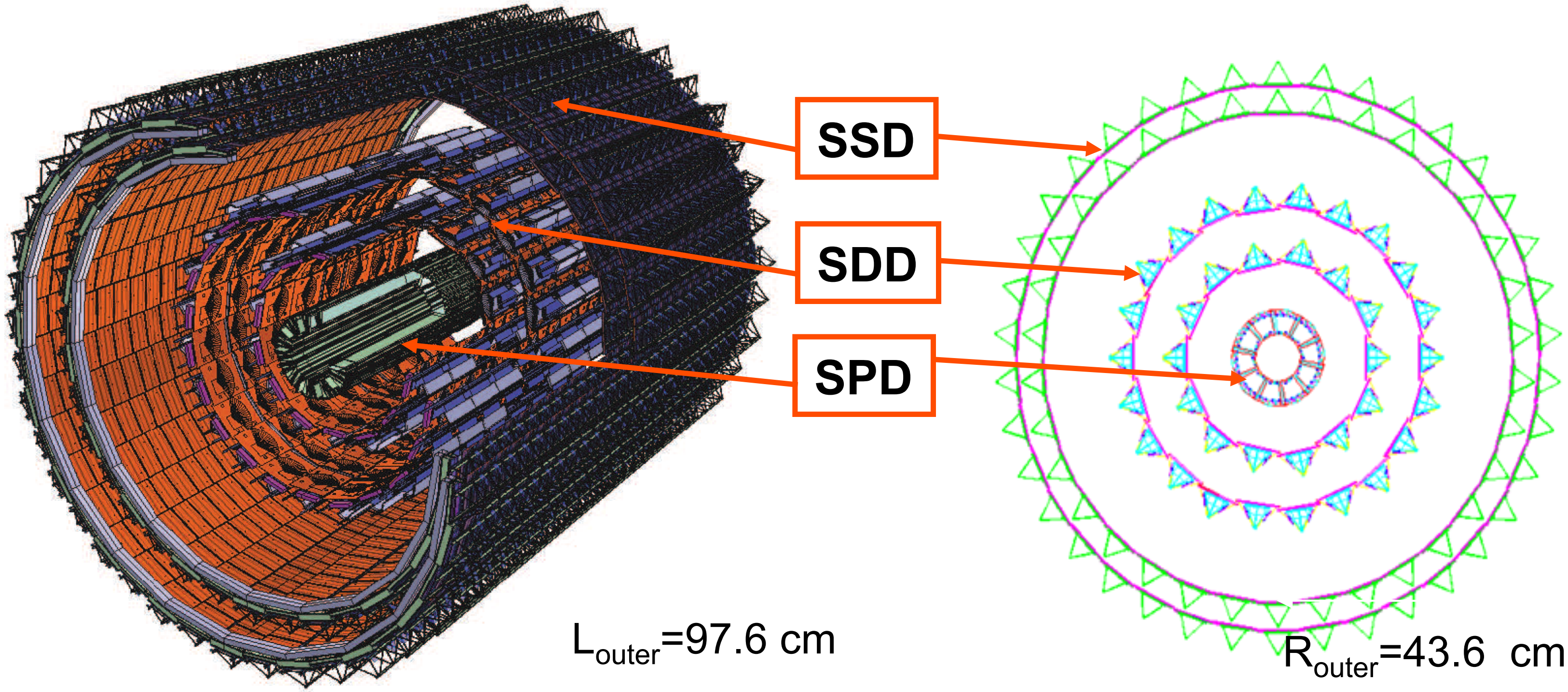


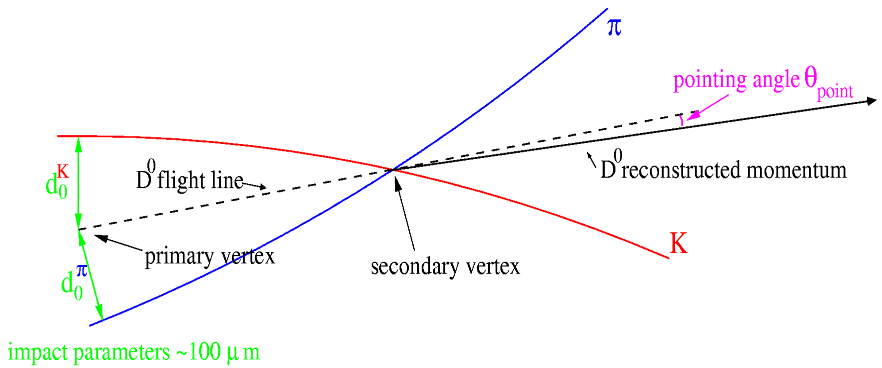
Kaon, pion RAA similar

$p_T \geq$ ~8 GeV: All hadrons similar

Partonic origin of suppression?

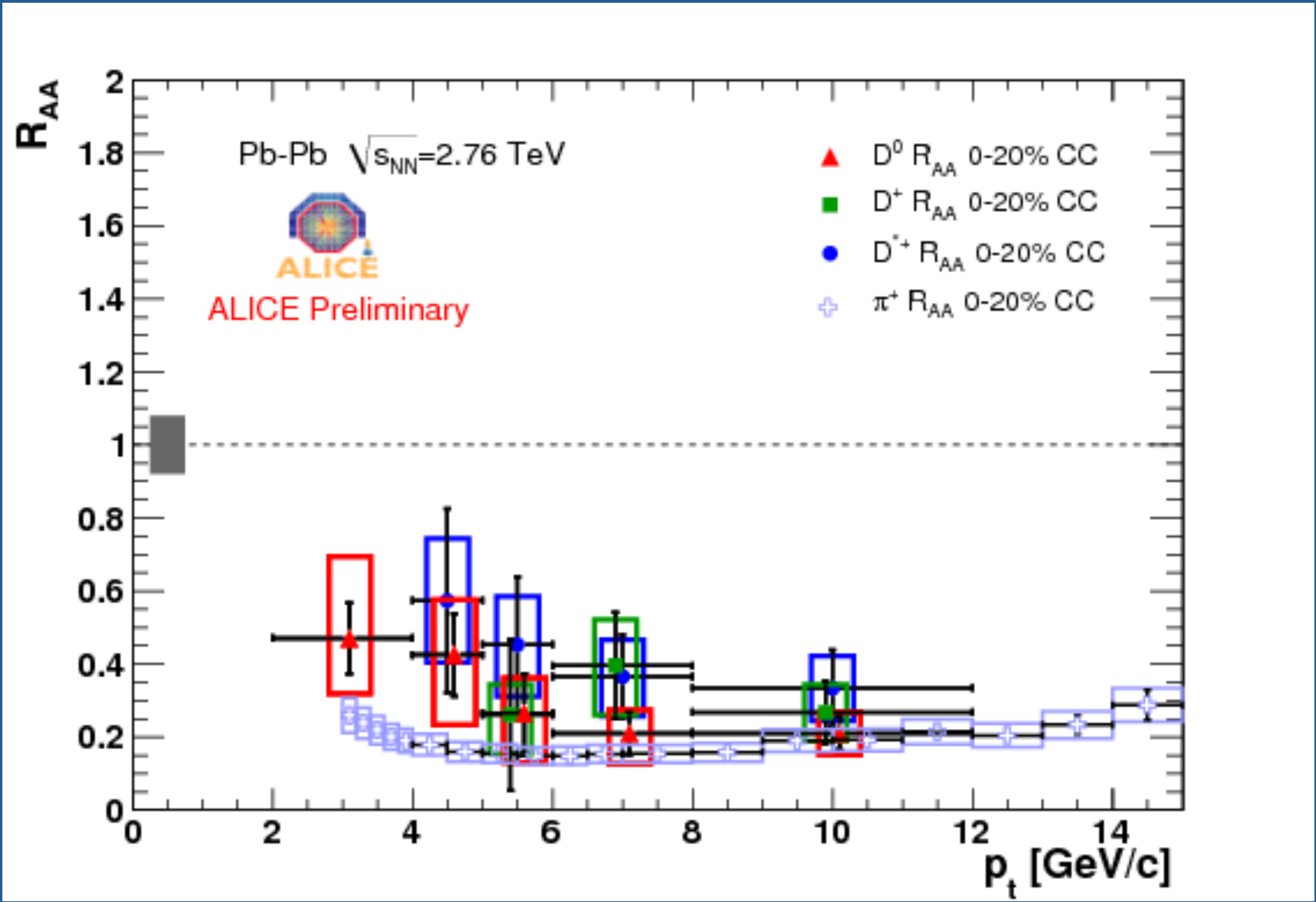
Insert: Mesons with Charm



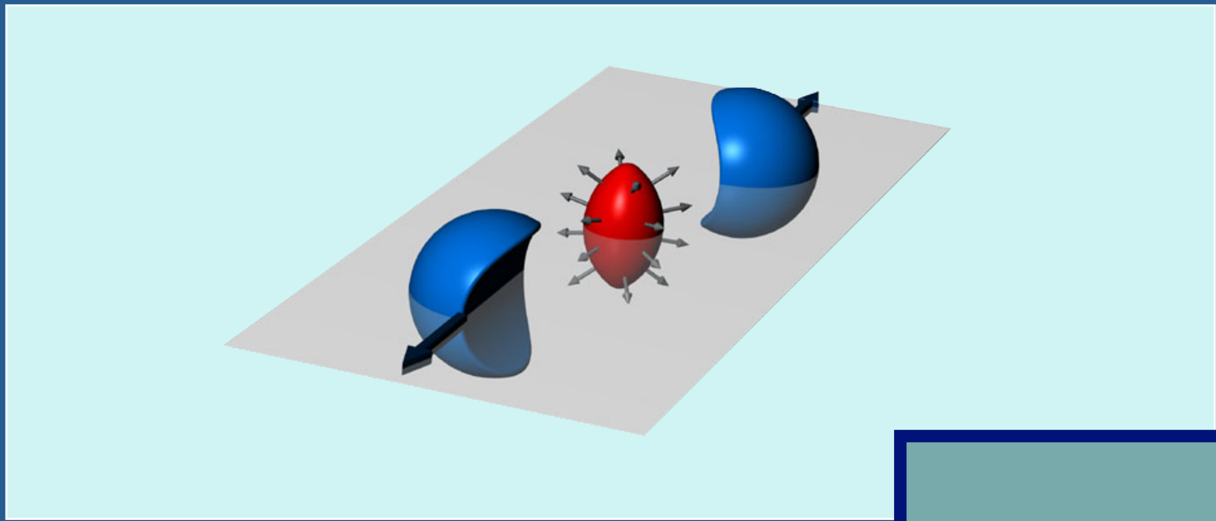


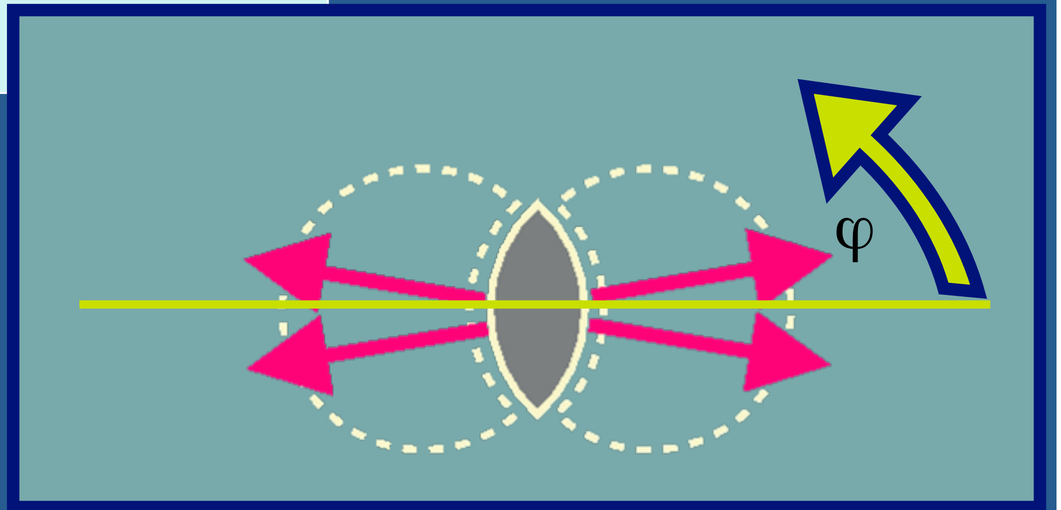
- secondary vertex reconstruction resolution <100 μm

Charm Nuclear Modification

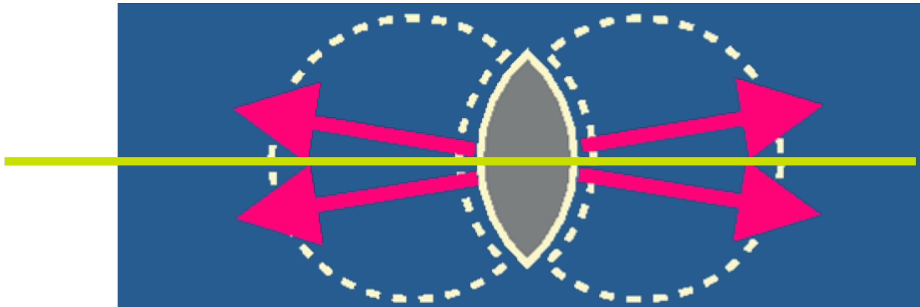


Path Length Dependence

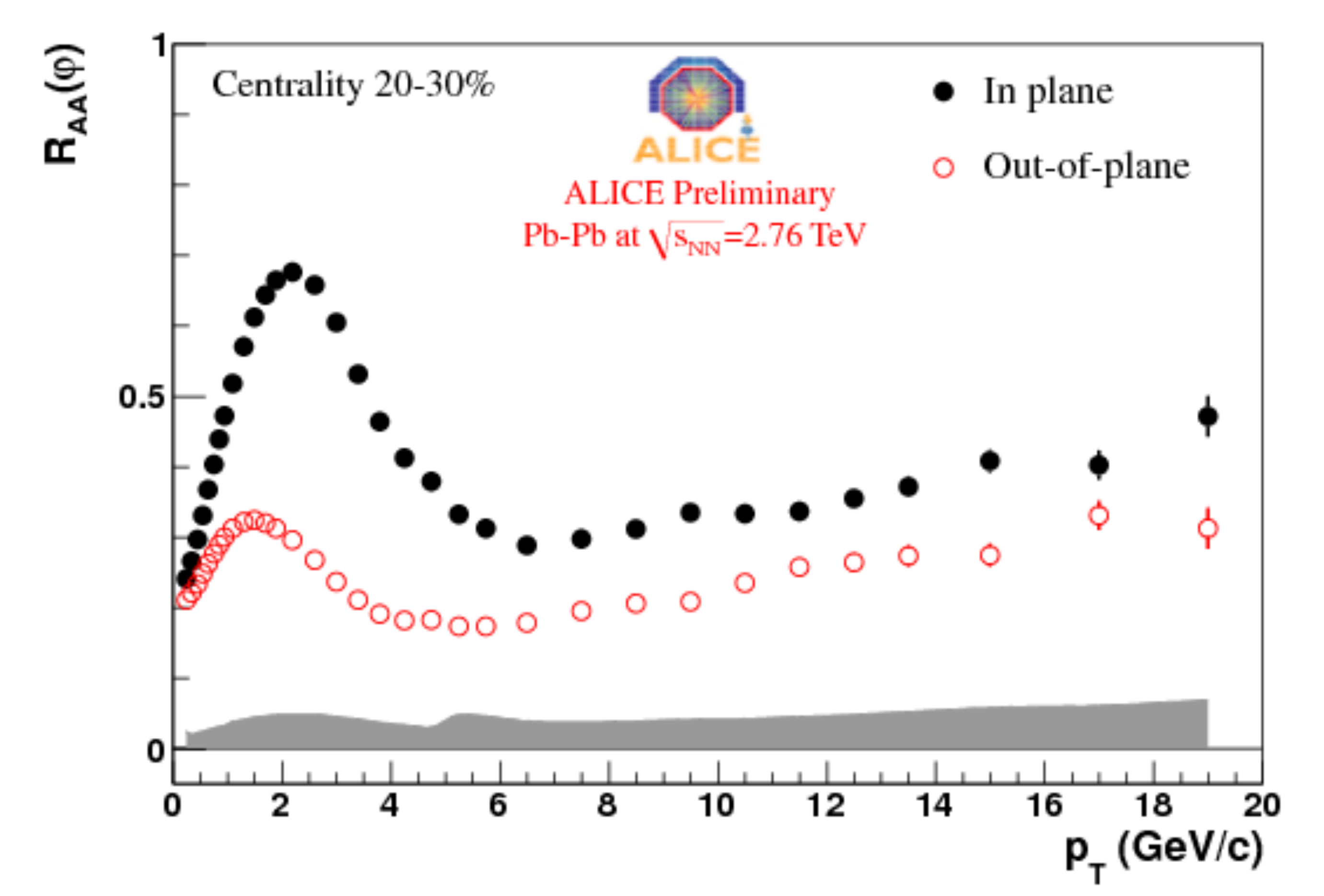




$$\frac{dN}{d\varphi} = C * (1 + 2 \cdot v_1 \cdot \cos\varphi + 2 \cdot v_2 \cdot \cos 2\varphi)$$



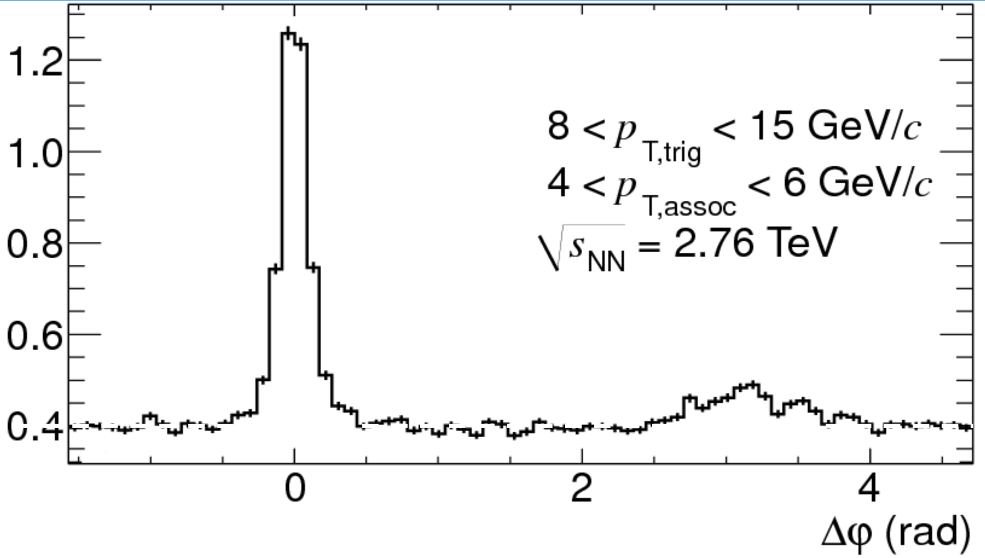
In-plane, out-of plan R_{AA}



Larger suppression out-of-plane:
Path length dependent energy loss

Di-Hadron Correlations

Di-Hadron Correlations

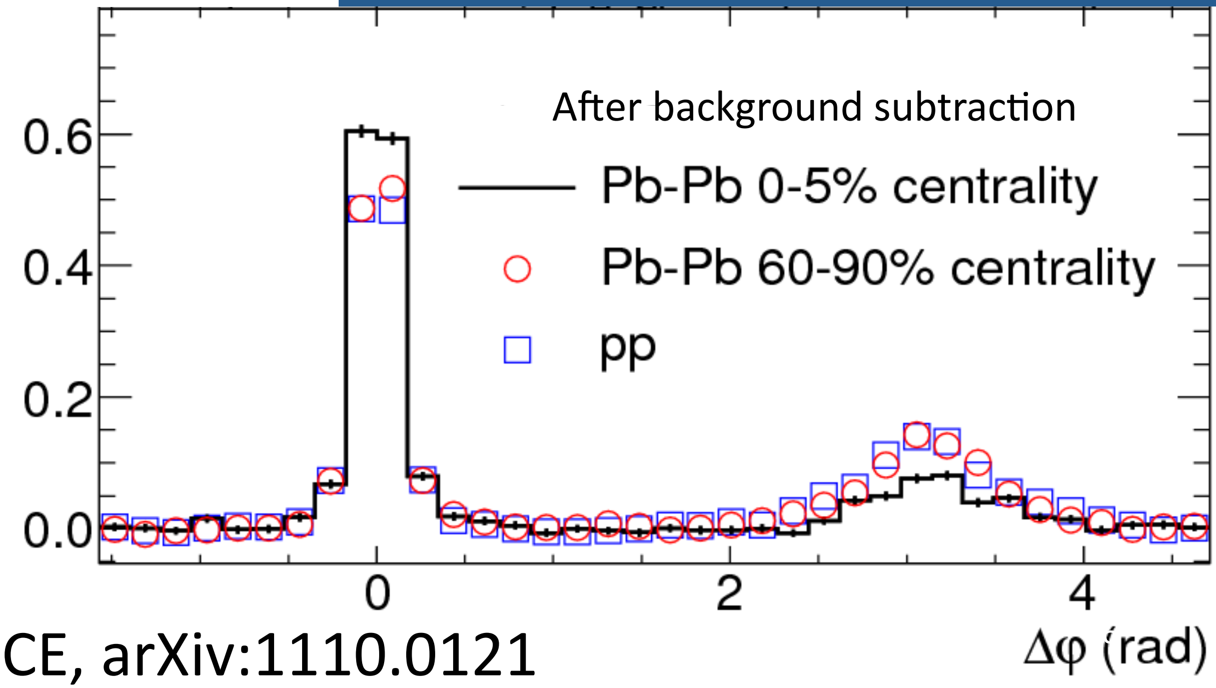


Compare AA to pp

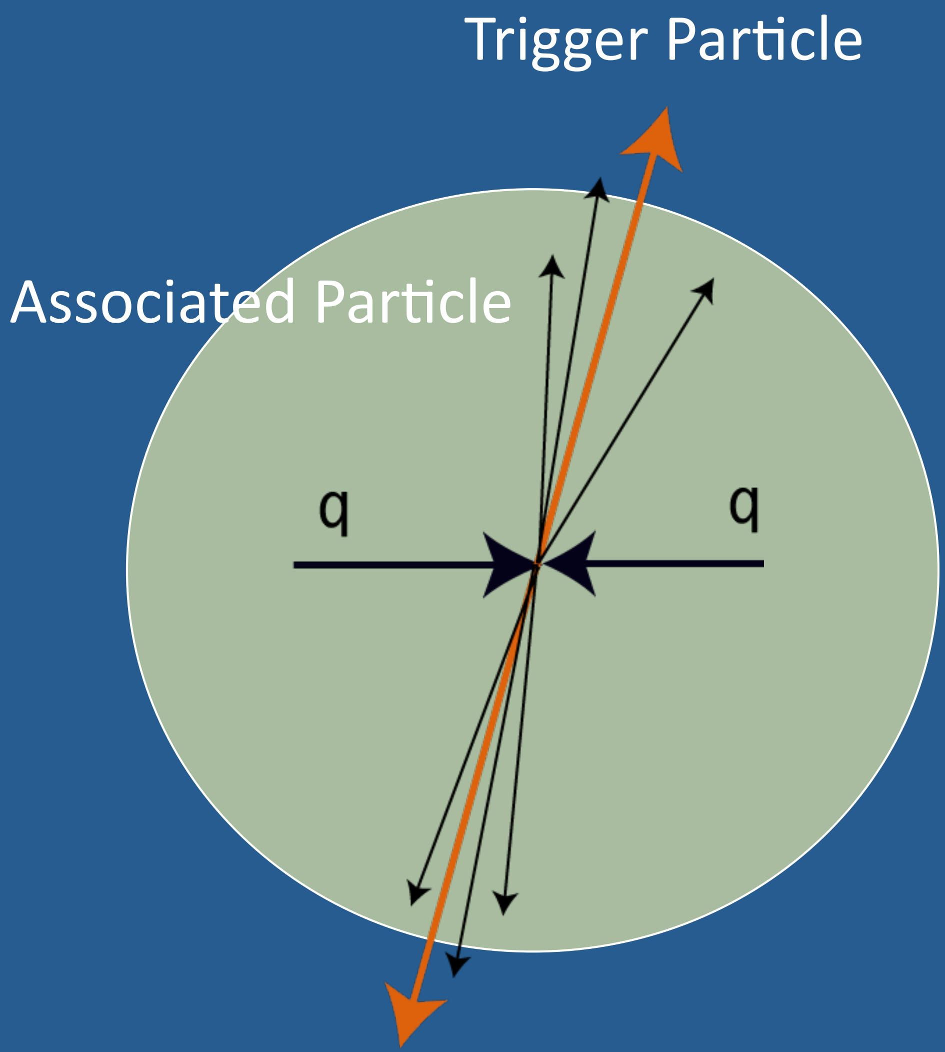
Near side: yield increases

Away side: yield decreases

Energy loss+fragmentation



ALICE, arXiv:1110.0121



Yield for the associated particles

for a given trigger

=

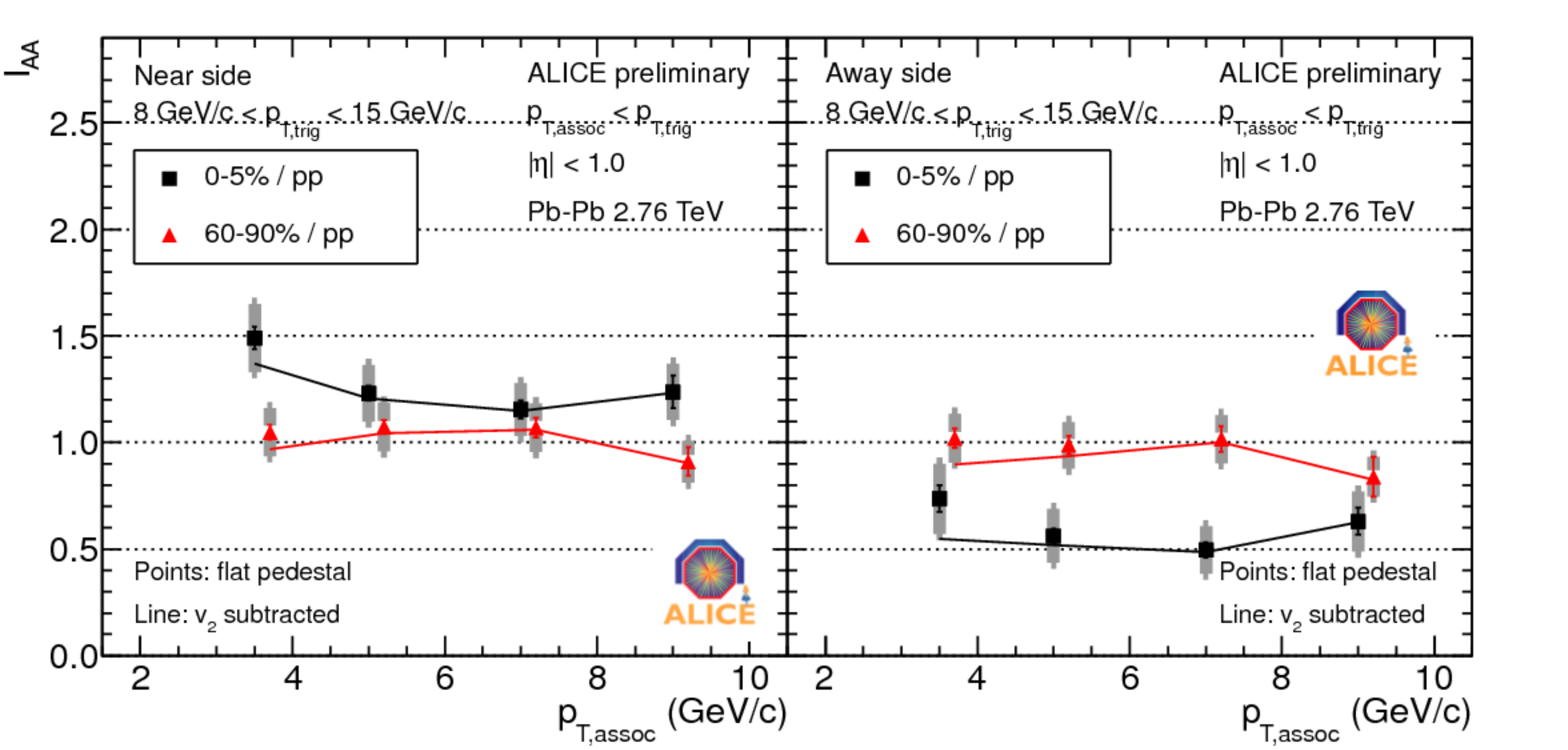
Per trigger yield

$$R_{AA} = \frac{1/N_{AA}^{evt} \cdot d^2N_{AA}/dp_T d\eta}{\langle N_{coll} \rangle \cdot d^2N_{pp}/dp_T d\eta}$$

I_{AA}

Di-Hadron Suppression

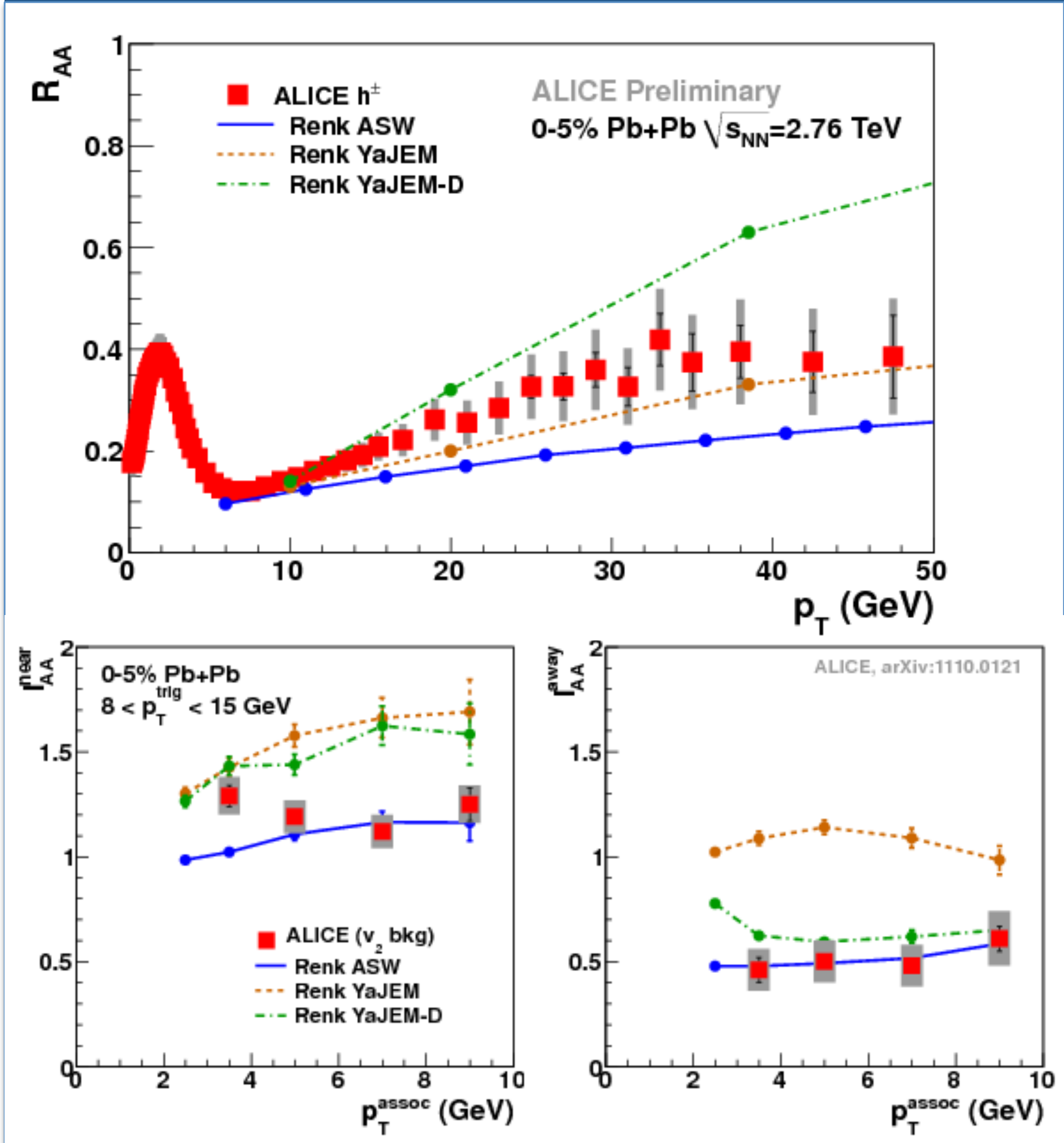
Near side | Away side



Near side: enhancement
Energy loss changes underlying kinematics

Away side: suppression
Energy loss reduces fragment p_T

Di-hadrons and Single hadrons



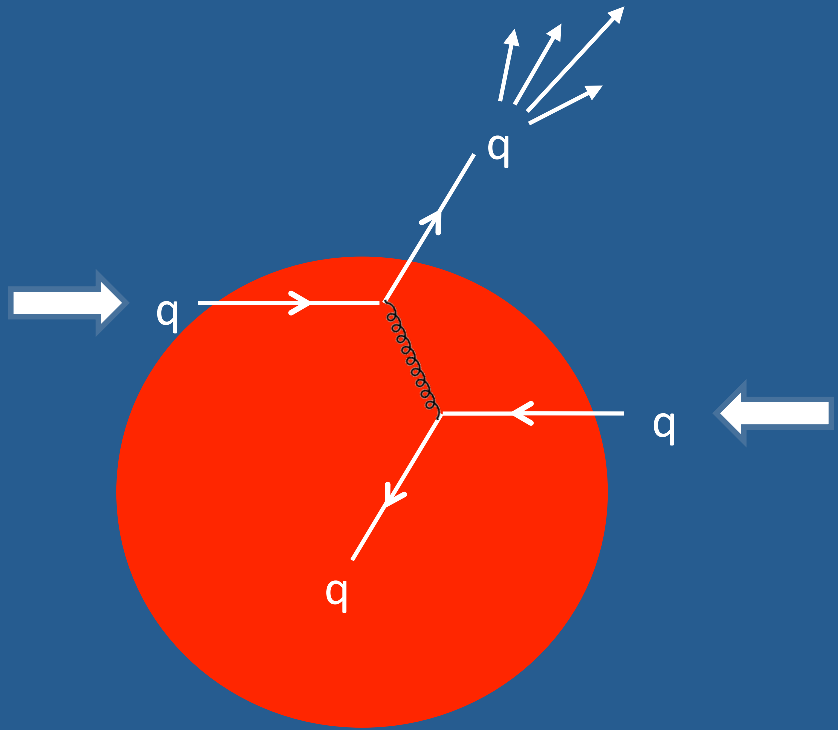
Energy loss calculations depend on:

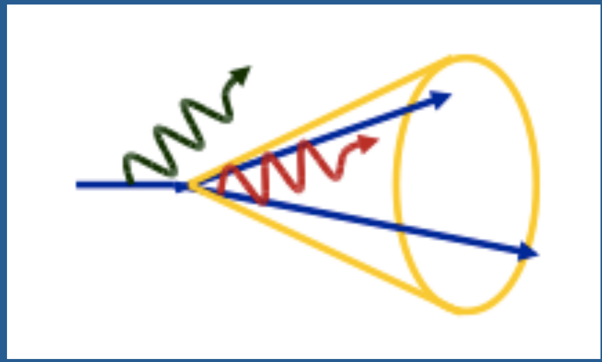
- -Initial production spectrum
- -Medium density profile/evolution
- -Energy loss model

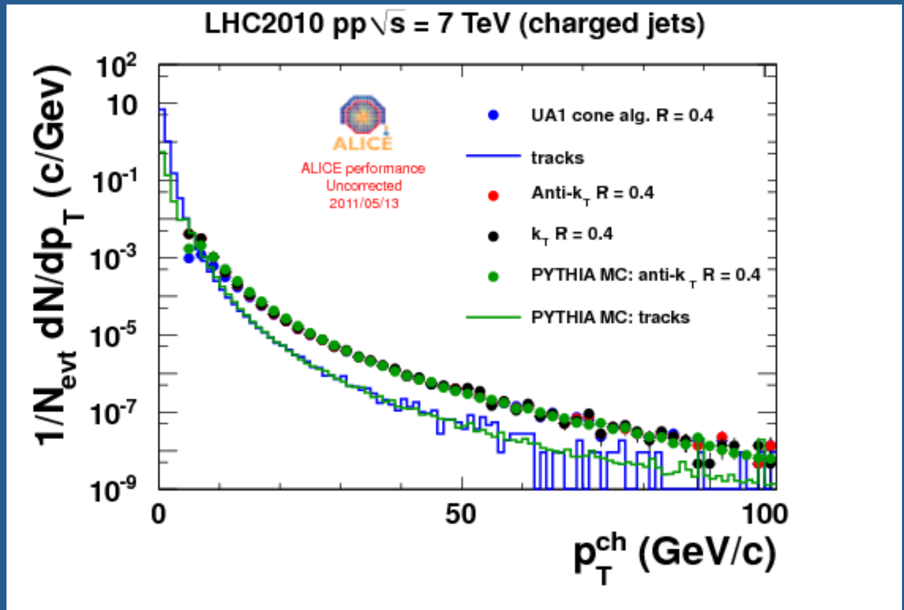
Need of simultaneous comparison to several measurements to constrain all aspects

Next steps

Jets Reconstruction

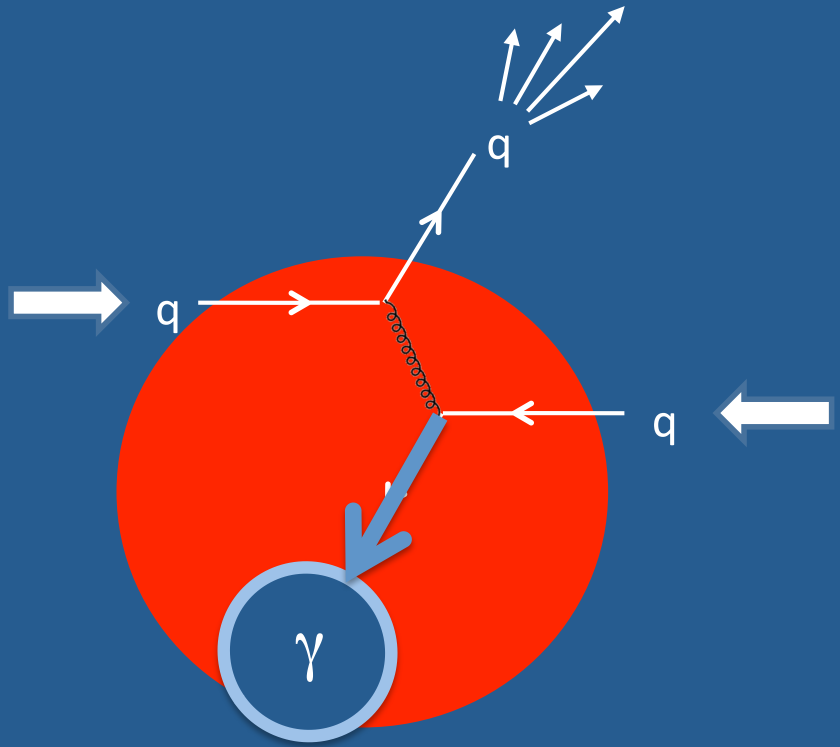


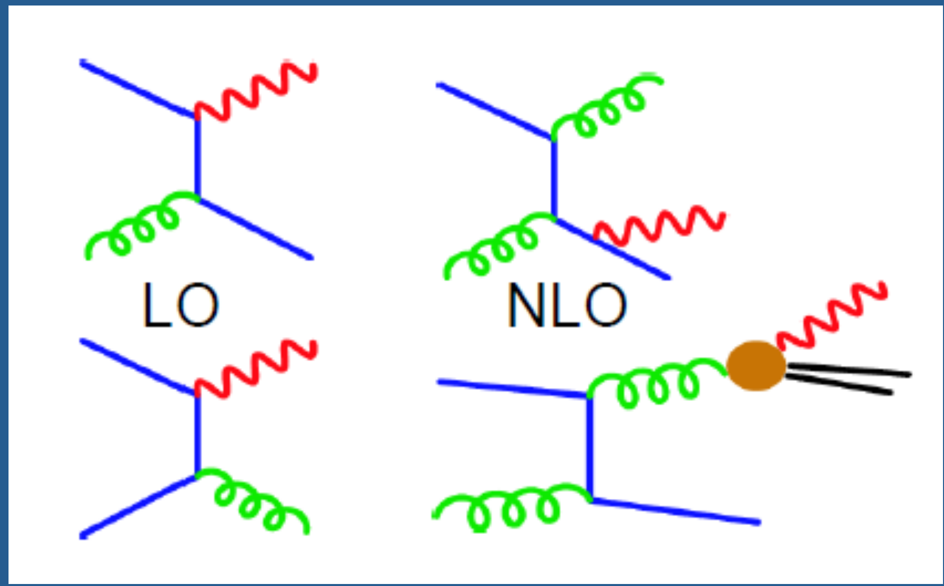


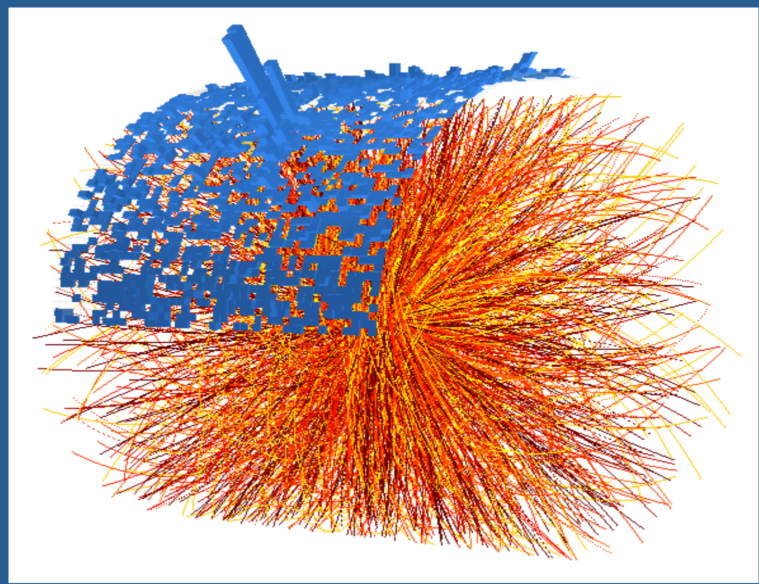


Background fluctuations
Underlying event

Photon Tagged Jets







High rates needed
2011: big fraction triggered data

Conclusion and Outlook

- First round of parton energy loss results available at LHC:
  - Single hadron, di-hadron suppression
  - R_{AA} similar for all measured hadrons at $p_T > 8$ GeV
  - Dependence on reaction plane angle
  - Heavy quarks (charm only for now)

- Need careful comparisons with theory
- Jet reconstruction being worked on

- 2011: factor ~10 increase for main results
- p+A run in 2012